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Blytt
Cause of displacement of beach-lines

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The probable cause of the displacement of beach-lines

An attempt to compute geological epochs

By

A. Blytt

(Christiania Videnskabs-Selskabs Forhandlinger 1889. No. 1)

(With a table).

Christiania
I Commission hos Jacob Dybwad
A. W. Brøggers Bogtrykkeri
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The probable cause of the displacement of beach-lines

An attempt to compute geological epochs

By

A. Blytt

(Presented to the Society 9 Dec. 1887 and 1 June 1888).

This Paper is an attempt to explain in greater detail, and to substantiate hypotheses which I already five years since propounded. It contains an attempt to introduce a means of computing geological time. It is presented without making any further claim for it than being what Englishmen call „a working hypothesis.“ It was the distribution of plants that first led the author to consider this important subject, but the problem of geological time cannot be solved without calling to our aid, it may well be said, the whole of the natural sciences. The problem can consequently not be solved by any one man. Whilst I now propound my hypothesis, I would crave the indulgence of my readers for the many imperfections which must attend such an attempt, and I venture to hope that the hypothesis may, at any rate, be found worth a minute examination.

After I had attempted to show, in a series of Memoirs on the distribution of plants, the peat mosses, the old beach-lines, the terraces, and the series of moraines, that climate is subject to periodical alterations; I published a Paper, (Chria. Vid. Selsk. Forh. 1883 No. 9, translated in Biolog. Centralbl. Erlangen 1883 no. 14—15): On the Alternation of Strata and its probable importance in the Computation of Geological Time and the Study of the Changes of Species. The essential contents of that Paper, so far as concerns the problem of geological time, were as follows:

Alternation of strata, by which is to be understood an alternation of geological beds of different natures, may be produced by rapid temporary changes in the local relations, without the aid of general and more permanent causes.

But causes of the last-named kind also exist, which produce alternation of beds. Two such periodically active causes may be traced in the series of geological beds; one short one, returning at somewhat regular intervals, and another longer and more irregular one. The firstnamed produces an alternation of the climate, as the velocity of the ocean currents throughout thousands of years is supposed to increase and diminish alternately; the last named, longer period, produces a rise and fall of the sea in relation to the land, and an alternation of deep-sea formations with littoral formations or fresh-water beds. The supposition is expressed that those periods, traceable through the series of beds, may possibly stand in connection with the two cosmic periods discovered in astronomical science, the precession of the equinoxes, and the changes in the eccentricity of the Earth's orbit; but the Paper referred to does not attempt to show in what manner such a connection arises. Whit the aid of these two hypotheses, however, a factitious series of beds may be constructed, and it appears that such a series, containing no less than 37 alternations of strata, may again by recognized, layer by layer, in the Tertiary formations of the basin of Paris.

This result encourages still further to test the correctness of the two suppositions. In regard to precession the attempt is already made, in my Memoir on the Probable Cause of the periodical Alteration of the Velocity of the Ocean currents (Chria. Vid. Selsk. Forh. 14 Dec. 1883; Biolog. Centralbl. Erlangen 1884 n. 2).

The material substance of that Memoir is as follows: The precession of the equinoxes causes the summer to be, for about 10,500 years, longer than the winter, but in the subsequent 10,500 years to be shorter. This relation is reversed in the northern and southern hemispheres. The difference between the number of winter and summer days increases with the eccentricity of the Earth's orbit.

The cooling of the Continents in the higher latitudes during winter, produces low atmospheric pressure over the seas. These low atmospheric pressures exhaust the air from the southern latitudes and from this cause south-westerly winds prevail in the North Atlantic Ocean.

During winter the south-westerly winds of the North Atlantic Ocean are, therefore, owing to the great reduction in the temperature of the interior land, usually, thrice as strong as in summer. In the semi-period, when the winter occurs in aphelion, the mean annual velocity of the wind becomes, consequently, greater. Now, it is the prevailing winds that produce the grand ocean currents, such as the warm stream of the North Atlantic Ocean. The velocity of the ocean currents is dependent on the mean velocity of the winds during the last great division of time. As, now, this mean velocity of wind is periodically changeable, owing to the equinoctial precession, therefore the velocity of the ocean currents, and the temperature of the waters must, consequently, be subjected to a periodical change.

For about 10,500 years that warm current will increase in velocity and temperature; and, again, in the following 10,500 years will diminish, and will continue to alternate thus throughout all time.

When winter occurs in aphelion, the difference between coast-climate and inland-climate will become more distinct. The motive-power of the ocean currents will increase and diminish by from 1 to 5 per cent of the mean annual value, according as the winter may occur in aphelion or in perihelion, and according to the greater or lesser eccentricity of the Earth's orbit.

Such an alteration in the velocity of the ocean currents will produce an alternation in the climate, which, it is true, may not be very considerable, but will still be sufficiently great to leave its traces on the strata. During cold and dry periods, the rivers are in a great measure nourished by springs. That water has filtered slowly through the strata and is rich in soluble substances, but its small volume and gentle velocity causes it to carry with it less clay, sand and gravel. During rainy periods the rain-water washes a mass of such substances down, but it passes quickly away, and as it flows principally on the surface it does not have sufficient time to dissolve much. The springs also flow more freely during rains, but their waters become more mixed with the surface rain-water. The rivers become, thus, proportionally poorer in soluble matters, but have a greater volume, and the accelerated current carries with it more clay, sand, and gravel into the estuaries. The dry periods will therefore be relatively richer in purely chemical deposits taken up in the clearer waters, and the rainy periods in mechanical deposits. Layers of both kinds will of course be formed at all times, but they will be deposited in different places according to the variable amount of rainfall. I therefore conclude that when thick beds of alluvial sand and clay alternate, when soft clay and marl alternate with hard marl and lime, when thickish layers of loose sand alternate with sand-stone which is cemented with chemically deposited cements (iron, silicic acid, lime), when clay alternates with layers of septaria etc. then do the first-named beds, at any rate, date from periods with warmer ocean waters and greater rainfall; that is the same as to say, as regards Western Europe, from periods with winter in aphelion.

That this alternation of strata is due to a period of several thousands of years duration, may be gathered from this fact, that the fossils vary quickly upwards through the beds. In the Tertiary formation only few, often only 4 to 5 such alternations of strata occur in each stage. The entire Oligocene epoch contains only about 30, the Miocene still fewer, and the Pliocene scarcely 20 such alternations of strata.

In this manner precession has, in my opinion, left its imprints on the strata, and these should thus become a means of measuring geological time. The greater the eccentricity of the Earth's orbit has been, the more distinct will the traces of the period be; when the path approached the circular form the traces of the period will become less distinct.[1]

Whilst I refer my readers to the Memoirs already named, and to my Paper on „Variations of Climate in the course of Time“ (Letterstedtske Nordisk Tidsskrift 1885 in English, in Chria. Vid. Selsk. Forh. 1886 No. 8 and „Nature“, London 8 and 15 July 1886), I will pass on to examine whether there is any reasonable ground for assuming that also the second supposition is correct; whether it is possible that the level of the seas rises and falls in higher latitudes with the eccentricity of the Earth's orbit.

Large portions of the Earth's surface consist of layers which still lie undisturbed in their original level position. These portions *Suess* has called tables. But in many parts the terrestrial crust is so cut up by cracks and fissures that it may be likened to a breccia. The broken parts are often displaced, in relation to each other, thousands of feet. Beds which originally lay level have become folded, „bed-thicknesses of 7—8000 feet have become bent as if composed of straw“ (*Kjerulf*: Udsigt over Norges Geologi, Chria. 1879 p. 76). And the folded beds are upheaved high above their original level. Even such young sea-formations as those of the Eocene epoch, have been upheaved to heights of 21,000 feet above the level of the sea (*Suess* Antl. d. Erde I p. 564). Sometimes they stand perpendicularly, ore are even reversed so that older strata cover younger ones. Through the fissures eruptive masses have been ejected, and have covered thousands and thousands of square miles. And the division between land and sea alternates. It is true, it has been assumed that the great ocean depths and the great continents have, in all essential respects, retained their original relations to each other from the remotest times, but the beach-lines oscillate periodically backwards and forwards. And these changes in the surface of the earth have taken place from the remotest times, and still remain in activity in our own days.

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[1] But the perihelion also oscillates backward and forward. The period between two aphelions at the winter solstice, therefore, varied in the post-glacial times to the extent of as much as 6400 years. That must have some influence. The longer the duration of a period, with aphelion during winter, the longer would the warm current of the Atlantic Ocean increase in velocity, and the greater would the alteration of the climate become. The mild period, in which Bergen marine fauna existed in Christiania Fjord, and which has also left traces in other places on our hemisphere, was, in my opinion, the consequence of an unusually long period of winter in aphelion. The winter solstice occurred in aphelion (cfr. Croll), 61,300, 33,300 and 11,700 years ago. The middle of the Atlantic period, with Bergen marine fauna in Christiania Fjord occurred, according to the testimony of the peat mosses, 33 – 34,000 years ago, consequently subsequent to the 28,000 year period.

Geologists usually seek the explanation in the cooling and contraction of the body of the Globe. The crust becomes folded, just as the skin of an apple wrinkles when the apple dries. The leading geologists of modern days adopt that view, and *A. Geikie* says in his Textbook of Geology (London 1882 p. 287), certainly with good reason: „With modifications the main cause of terrestrial movements is still sought in secular contraction.“

According to that doctrine, the changes in the crust of the earth depend upon the interior contracting more rapidly than the crust, so that the latter becomes too large, and the force of gravity draws it downwards. In that manner great forces arise, acting horizontally upon the crust, which must thus become folded, and crack in some places. The broken parts fall inwards, and there is thus formed what *Suess* calls „Einbrüche.“ If a part of the crust remains in its old position whilst all around sinks, there is formed what *Suess* calls a „Horst.“

The old doctrine of forces acting perpendicularly, upwards from the interior, is rejected by *Suess* in the most decisive manner. Both he and *Heim* have, by their investigations of the

Alps, shown that the folds in the Alps are produced by lateral forces, and that such a lateral force is capable of upheaving great mountain ranges into the air. But *Suess* goes still further; as in a Memoir „Über die vermeintlichen säcularen Schwankungen einzelner Theile der Erdoberfläche“ (Verh. d. K. K. Geol. Reichsanst. Wien 1880 p. 171 ff.) he even denies the existence of any upheaval produced by internal perpendicularly acting forces; neither mountain nor continent has been upheaved in that manner. He says (l. c. p. 180): „Es giebt keinerlei verticale Bewegungen des Festen mit Ausnahme jener, welche unmittelbar aus der Faltenbildung hervorgehen. Wir werden uns entschliessen müssen die Doctrin von den säcularen Schwankungen der Continente zu verlassen.“

A. de Lapparent sharply criticizes *Suess'* doctrine in regard to „Horste“ (Bull. de la Soc. Géol. de France ser. III tome XV p. 215 ff.) but yet agrees with him in the belief that the cooling of the Globe has produced large folds in its crust, and he denies every upheaval not produced as a result of folding. He says, for instance (l. p. c. 217): „Il ne s'agit pas d'avantage d'opposer à la doctrine des soulèvements absolus, produits par des forces qui agiraient directement de bas en haut, une protestation devenue sans objet car les partisans des impulsions verticales sont, de nos jours plus que clairsemés et, en dehors de quelques rares attardés, personne n' oserait encore attribuer à une telle action une part sérieuse dans la formation des montagnes.“ And he makes no reservation, so that it must be assumed that neither does he acknowledge forces, acting from beneath to elevate entire stretches of land.

It appears that an essential ground for *Suess* to deny forces acting vertically from below, lies only in the fact that he is entirely unacquainted with any such force that could possibly produce such an upheaval (vide „Antlitz der Erde“ Prague and Leipzig 1885. I p. 741).

Hutton's and *v. Buch's* doctrine of the action of such forces appears therefore to be rejected by modern geologists. But yet there remain a few who still maintain related opinions. *I. C.*

Russel, for instance, says (U. S. Geol. Surv. 4th. Ann. Rep. Washington 1884 p. 452—53), that the faulting in „the Great Basin" is not a consequence of any lateral compression, but is accompanied by an extension in a horizontal direction. „The fractures are closely related to an extension of the strata caused by upheaval." To me it appears improbable that such relations can be explained as the consequence of folding. And *C. E. Dutton* (U. S. Geol. Surv. 6th Ann. Rep. Washington 1885 p. 198) says of the mountainous masses in Western North America, whilst he, at same time, acknowledges that many ridges are folded by a lateral force, „The mountains of the west have not been produced by horizontal compression, but by some unknown forces beneath, which have pushed them up!"[1] It is not my intention to maintain that the cooling has no share at all, in giving to the surface of the Earth the form it now possesses, but I think that a new theory is necessary, which although it may possibly not entirely displace the old doctrine, may yet serve to explain features that the old theory leaves unintelligible.

Henry H. Howorth has written two Memoirs: „Recent Elevations of the Earth's Surface in the Northern Circumpolar Regions" (Journ. Roy. Geogr. Soc. Vol. XLIII. London 1873. p. 240) and „Recent Changes in the Southern Circumpolar Regions" (l. c. Vol. XLIV. London 1874. p. 252).

In these Memoirs he has collected together what was known at that time as to the displacement of the beach-lines in the latest geological age, and the main result of his investigations is summed up in the following words: „The South Pole, as well as the North, is a focus of protrusion, the land around it is being gradually elevated.“ The land has, in the latest geological age, i. e. in the postglacial time, generally speaking, become lowered in the lower latitudes and upheaved in the higher latitudes.

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[1] The current doctrine of cooling and contraction is attacked by *Peirce* in a lecture delivered in the Amer. Academy 11 May 1869 (vide Proceed. Am. Ac. Arts and Science Vol. VIII. Boston and Cambr. 1873 p. 106); also by *O. Fisher:* Physics of the Earth's Crust. London, 1881 and by *Dutton* in „A Criticism upon the contractional Hypothesis" (Am. Journal of Science. Ser. III, Vol. VIII p. 113 ff. 1874). All consider that the contraction is insufficient to explain the facts, indeed the last-named considers that the facts tell against it. *A. de Lapparent* attempts, on the other hand, in his Memoir: Contraction et refroidissement du globe (Bull. de la Soc. Géol. de France Ser. III Vol. XV Paris 1887 p. 383 ff.) to show that it is perfectly sufficient.

Suess arrives at a similar result in the above-named Memoir (Verh. d. K. K. Geol. Reichsanst. Wien 1880 p. 174—175). He has also studied the displacement of the beach-lines of the whole earth, in the age immediately preceding our own, and collects the result of his investigations in the following words: „Es zeigt sich terrasirtes Land (i. e. land lately upheaved, in relation to the sea) in den hohen nordischen Breiten allenthalben, soweit noch der Mensch in diesen Einöden vorgedrungen ist. Ebenso reicht dasselbe weit, wenn auch nicht allenthalben gleich weit, in die gemässigten Breiten herab, doch allgemein an Höhe abnehmend. Mit anderen Worten, ringsum den Nordpol und bis weit herab ist die Summe der negativen (i. e. depressing) Bewegungen der Strandlinie grösser als jene der positiven, gegen Süden hin nähern sich jedoch diese beiden Summen mehr und mehr.

In den tropischen Wässern, in den Regionen der Corallenbauten, tritt der entgegengesetzte Fall ein, es überwiegt die Summe der positiven Bewegungen.

Weiter gegen Süden, etwa über den 25—35° südl. Breite hinaus, beginnt in Süd Amerika, in Süd Afrika, Süd Australien und Neu-Zeeland abermals das Terrassenland des Nordens, d. h. dasselbe Uebergewicht der negativen Bewegungen mit demselben oscillirenden[1] Charakter wie im Norden.“ The exceptions are (cfr. *Suess*) few and of slight importance.

Howorth and *Suess* have, therefore, both arrived at the same result. But their explanations are opposed to each other. *Howorth* believes that it is the land that is upheaved in high latitudes, and that the earth swells up, as it were, in the proximity of the poles, and is constricted in the tropics. *Suess* declines to acknowledge any other upheavals than those produced by folding, and believes that it is the sea which has flowed towards lower latitudes. He indicates as a possible explanation, changes in the length of the sidereal day and centrifugal force. But this change should, then, have acted only on the sea, and as the sea flowed towards the equator, the sidereal day should, thus, have become considerably shorter in the latest geological age. We shall subsequently see that there is no reason whatever known to us, which could have produced such an abbreviation of the day sufficient to explain what *Suess* desires explained. The old doctrine of cooling is scarcely sufficient to explain the relations upon which *Howorth* and *Suess* lay stress. Even *Suess* who is a zealous adherent of the doctrine of contraction is here obliged to seek another explanation.

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[1] In this expression *Suess* points to the circumstance, that the ancient beach-lines occur on several levels above each other. He fancies that each of these levels indicates an oscillation of the sea. I believe that the larger number of these levels is only a result af climatic alternations caused by the precession of the equinoxes (vide Engler's Bot. Jahrb. II. Lpz. 1881 p. 24 ff.).

Another theory however arises in our day, a doctrine that is doubtless destined to take an important place in the study of geology. It originally emanates from the celebrated Philosopher *J. Kant.* In 1754 he wrote a Memoir: „Untersuchung der Frage ob die Erde eine Veränderung ihrer Achsendrehung erlitten habe.“ In it he shows that the sea, by reason of the lunar and solar attraction, is in constant movement contrary to the direction of the earth's daily rotation. The friction of the tidal-wave against the sea-bottom and the coast deprives the rotation of a portion of its energy, and acts continually in the same direction, so that the sidereal day must, from this cause, always gradually increase in length.

The Moon always presents the same side to the Earth, because the terrestrial tidal action on the still liquid lunar mass caused the rotation of the Moon to become continuously retarded until at last the Moon has been compelled to always present the same side to the Earth.[1] In the same way the Earth will, at some time in the distant future, come always to present the same side to the Moon. This view of Kant's is adopted as correct by the leading modern physicists; by such men as *Robert Mayer*, *Helmholtz* and *W. Thomson*.

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[1] Is it possible that the Moon's great abundance of old volcanoes may be explained, by the great change which its rotation, and probably, therefore, also its oblateness, has undergone? A. B.

There are certain relations connected with the movements of the Moon, which astronomers are disposed to explain by the assumption that the sidereal day slowly increases, owing to the friction of the tidal-wave. But on these subjects we will, here, only refer the reader to *Thomson* and *Tait's* „Treatise of Natural Philosophy“ and to a Paper by the first-named: „On Geological Time“ (Transact. Geol. Soc. Glasgow, 1868. Vol. III, Part I, p. 1 ff.).

Thomson and *Tait*, in their *Natural Philosophy*, treat of the rotation of the Earth. They state that there are various forces acting to change it; some of these act towards making the sidereal day shorter, whilst others, again, act in the opposite direction. The latter forces are the most powerful, and among them, again, the tidal-wave undoubtedly takes the most important place; so that for that reason the day becomes always longer and longer in the course of time. The cooling is the most important force that contributes to abbreviate the day, but its effect is estimated by Thomson (Transact. Geol. Soc. l. c. p. 28) at only $\frac{1}{8000}$ part of that of the tidal-wave; and the effect of the latter can not be counterbalanced by any of the other forces which act, sometimes in one and sometimes in another direction (transport of sediments from higher to lower latitudes, or *vice versa*, accumulation of ice at the poles and similar causes), and which in the course of time abolish themselves, whilst the tidal-wave always acts for millions of years in the same direction, (*Thomson*: Of Geological Dynamics, Transact. Geol. Soc. Glasg. 1869. Vol. III, part 2, p. 223).

In that way the sidereal day should always, therefore, become longer and longer. Now, what influence has that upon the Earth? If the Earth was entirely fluid, it is clear that it would immediately be compelled to change its form. According as the sidereal day became longer, and the centrifugal force diminished, its oblateness would necessarily become less. But, now, the old doctrine of an internal igneous mass is rejected by physicists, and *Thomson* supposes that the Earth is a solid body throughout. Now, would this solid body retain its form in spite of the lengthening of the day, or would it yield and accommodate itself to the change? The sea would of course immediately do so, and according as the centrifugal force diminished, it would sink in lower and rise in higher latitudes. We know that the present form of the Earth corresponds, at any rate somewhat closely, to the length of the day. At present its flattening is just about what is due to its present rotation, as worked out by calculation. If, now, it can be shown probable that the Earth, since it obtained a solid crust, has lost so much of its rotation that the day has become several hours longer, then the circumstance that the oblateness corresponds to that due to the rotation, seems to show that the solid Earth has really altered its form. Jupiter and Saturn have sidereal days of, respectively, 9 h. 55 m. and 10 h. 15 m., and an oblateness of respectively $\frac{1}{17}$ and $\frac{1}{10}$. In Mars, whose day is about 24 h. 37 m., observations have not been able to show, conclusively, any flattening. There therefore appears to be a connection between oblateness and rotation. But it may be objected that perhaps Jupiter and Saturn are still melted masses.

W. Thomson, and *Tait* even more, appear to be of the opinion, that the Earth would not alter its form. They suppose that it must have become solid not many millions of years ago, as the flattening corresponds somewhat closely to the rotation.

J. Croll (Climate and Time. London 1875 p. 335, *vide* also Am. Journ. of Science Ser. III. Vol. VII p. 457) thinks that the day became lengthened so slowly, that denudation would have time to act sufficiently on the Earth's form, that it would come to correspond to the length of the day. As the seas sink in the lower latitudes, the shores of the continents in these latitudes would also become lower, owing to the action of denudation, whilst in higher latitudes the rising sea would protect the shores, in such latitudes, from being acted on by denudation; and in this way alone the Earth would always, owing to the denuding forces, obtain a form that constantly corresponded to it's rotation. But that is evidently not the case. Suppose, for instance, the Earth to be formed of ellipsoidal layers having an increasing density inwards. When the centrifugal force diminished the equilibrium would become, in consequence, disturbed throughout the entire mass, and in the interior the strain would steadily rise. Indeed, not even on the surface can denudation alter the oblateness, because we now know, from the modern investigations of the deep seas, that into these deep oceans, far from the continental shores, none of the disintegrated substances are carried out. Volcanic ashes and cosmic dust alone are deposited. Therefore, the action of denudation is not even sufficient to level the inequalities of the Earth's surface; still less the internal strain that the lengthening of the day produces. And, therefore, if the day has become considerably increased, the sea ought to have become collected at the poles and the land at the equator, if the solid Earth had not altered its form.

Others think that the Earth really must alter its form. The first to give expression to this is, as far as I can trace, *Herbert Spencer*. He wrote in the Philosophical Magazine (London 1847 p. 194) a short Paper: „The form of the Earth no proof of original fluidity", in which he contends that even the solid earth must alter its form if the centrifugal force becomes changed. When a body increases in size its power of resistance to rupture alone increases with the square of its dimensions, whilst the tendencies to rupture increase in the same proportion as the mass of the body, and therefore as the cube of the dimensions. When the size increases, we therefore arrive at a point when even the most solid body must yield to the forces acting on it. We must, therefore, Spencer states, assume that the Earth from its size, must yield and alter its form if, for instance, the centrifugal force becomes altered; because the hardest substance known to us would, exposed to the same forces as act on the earth, reach the limit of elasticity ere it attained one thousand millionth part of the size of the Earth. This demonstration is in *Prof. Schiøtz's* opinion not maintainable. In any case, I think that *Spencer* is the first who has expressed the opinion that even the solid Earth is capable of altering its form. In the previously named Lecture, in 1869, *Peirce* states that the lengthening of the sidereal day has most probably induced an alteration in the form of the Earth. And *Principal Dawson* states, in his „Story of the Earth and Man" (London 1887 ed. 9 p. 291) that this alteration of form, caused by the lengthening of the day, may probably occur at greater or lesser intervals. As long as the crust of the Earth does not yield, the waters will flow to the Poles, but when the strain becomes so great as to cause the hard crust to crack, the equatorial regions will become lowered, and the waters will again flow to the equator.[1]

In Philos. Transact. 1879 parts I—II *Prof. G. Darwin* has written a Paper, the results expressed in which are, shortly, as follows: he assumes that the Earth possesses a small degree of plasticity, and he estimates the internal friction that the tidal action of the Moon and Sun would produce in such a body. He thinks that both the sidereal day and the month have become much longer, and that the distance of the Moon has increased; that the obliquity of the ecliptic has diminished, and that a large amount of internal heat has been generated by the internal friction. According to his calculation, the sidereal day was, 46,300,000 years ago, 15 h. 30 m. and the Moon's distance equal to 46.8 times the terrestrial radius (compared with 60.4 times now). But 56,180,000 years ago the sidereal day was only 6 h. 45 m. in length, and the Moon's distance only 9 times the terrestrial radius, and the duration of the month only 1.58 days ($\frac{1}{17}$th of its present value). The internal heat produced by friction during 57,000,000 years would, if presented at one time, be sufficient to raise the temperature of the whole Earth to 1700 ° Fahrenheit.[1]

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[1] Similar opinions are expressed by *Dr. E. Reyer*: „Die Bewegung im Festen" (Jahrbuch der K. K. Geol. Reichsanstalt. Wien Vol. XXX 1880 p. 543 ff.).

W. B. Taylor expresses himself in a Paper (Amer. Journ. of Science Ser. III Vol. XXX, 1885, p. 249 ff.) „On the Crumpling of the Earth's Crust," against the doctrine of the contraction of the Earth, and thinks that the lengthening of the sidereal day is the cause of the alterations in its crust.

A. Winchell (Amer. Journ. l. c. p. 417) attempts in a Paper „Sources of Trend and crustal Surplusage" to show that the diminishing centrifugal force has produced folds with a North and South direction.

J. E. Todd refers in a Paper „Geological Effects of a varying Rotation of the Earth" (Amer. Naturalist XVII No. 1 January 1883 p. 15 ff.) first to the various forces acting so as to accelerate or retard the rotation. He assumes that the rotation is sometimes accelerated, sometimes retarded, that it acts first on the seas and later on the crust, and that from this cause the waters sometimes rise, and sometimes fall, in relation to the land.

He concluded that the oblateness has steadily been diminished, „*the polar regions must have been ever rising, and the equatorial ones falling*, though, as the ocean followed these changes, they might quite well have left no geological traces.[2] The tides must have been very much more frequent and larger, and accordingly the rate of oceanic denudation much accelerated. The more rapid alternation of day and night (57,000,000 years ago the year contained according to D. 1300 days) would probably lead to more sudden and violent storms, and the increased rotation of the earth would augment the violence of the trade-winds, which in their turn would affect oceanic currents."

Tresca (Comptes Rendus 1864 p. 754; 1867 p. 809 and other places) has shown that ice, lead, indeed even cast-iron, even at ordinary temperatures, may be so greatly compressed that their internal particles become displaced in relation to each other, like the particles of a liquid. Iron in solid condition may, under severe pressure, be forced into cavities, and acquires the form of the surroundings. On section of such compressed pieces, it has appeared that the particles or crystals have arranged themselves with a flowing movement, according to the form of the space into which the piece had been forced.

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[1] This heat, produced by the internal frictional disturbance, must contribute to considerably retard the secular cooling. *Lapparent* has paid no heed to this in the previously named Memoir on the Earth's contraction and cooling.

[2] In a subsequent work *D.*, however, assumes that the beach-lines would be displaced owing to the lengthening of the sidereal day. (Nature, 2 Sept. 1886 p. 422).

Here we must also refer to the interesting investigations of *Reusch* on compressed conglomerates. Under the severe pressure that has acted on the crust, the pebbles in the conglomerate have been pressed out into lanceolate bodies, and these bodies have, besides, become folded (vide *Reusch:* Silurfossiler og pressede konglomerater i Bergensskiferne, Univ. Progr. Chria. 1882, p. 15, 117).

On account of the immense pressures existing in the interior of the Earth, we must assume that at a certain depth and onwards a plastic condition exists. A steady lengthening of the sidereal day would bring the equatorial regions especially to increase in weight. As long as the form of the Earth remained unchanged a steadily increasing pressure would act on the internal mass, from lower towards higher latitudes.

There is, as *Darwin* accentuates (Nature 2 Sept. 1886, p. 422), reason to believe that the Earth, eventually, when the pressure has attained a certain point, will yield. A stream of the plastic mass will be directed to higher latitudes, and continue until the Earth has approached the form corresponding to the length of the sidereal day. When we consider the numerous testimonies of changes having occurred in the solid terrestrial crust, and of the frequent upheavals and lowerings of the dry land in relation to the sea, we must, indeed, agree with *Darwin*, that this theory is more probable than that of *Thomson* and *Tait.*

By experiment, *Wertheim* has (cfr. *Fock:* Lärobok i fysiken. Stkhlm. 1861 p. 202, 219) shown that no definite limit of elasticity has really been found for any substance, but that they all, even under the action of quite gentle forces, are subjected to small permanent changes, especially if the forces act for a considerable time. Although we may not find any permanent change of form under slight strains, that arises from the circumstance that the force has not acted sufficiently long. The effect of the force is therefore dependent on time, when it has to overcome a considerable resistance. „Upon tension“, *Schiötz* states (Lærebog i Fysik. Chria. 1881 p. 65) „the elongation steadily increases, although quite slowly after it has once begun; therefore a load, that acting only for a short time would not produce any elongation, may perfectly well do so if permitted to act for a longer period. This is the case in general, and is not confined to elongation only; from this cause do metal springs lose their resilience with time, and beams become curved little by little. Upon long continued application a wire breaks under a less strain than it does on a short application.“

It appears to me, that there is here a force which must be able to cause disturbances in the solid earth. I think that this is „the unknown force from the deep“, which has upheaved the mountains of western North America, and which *Dutton* refers to. The sidereal day lengthens very slowly. The sea follows the slightest alteration in the length of the day and slowly rises in higher latitudes. But the solid crust opposes a resistance to change of form, and first begins to yield when the strain has attained a certain point. When that point is reached, the crust also begins to be upheaved in higher latitudes.

In the lower latitudes these movements occur in the reverse direction. The solid crust is probably more sluggish than the sea in its movements, and whilst the sea moves itself evenly and uninterruptedly, probably the change of form in the solid crust may take place more in paroxysms, with intermediate pauses in which fresh straining forces collect themselves for renewed action.

„The elevation of mountains“, *A. Geikie* states, (Textbook of Geology. London 1882 p. 917) „is, in most cases, due to a long succession of such movements“ and (l. c. p. 919) „the elevation of mountains like that of continents has been occasional and so to speak paroxysmal.“ The disturbances in the crust take place along the same fissures repeatedly (vide, for instance, *Brögger:* Bildungsgeschichte des Christianiafjords, Separataftryk. Chria. 1886 p. 78). Something similar takes place on volcanic eruption.

The eruptions are separated by shorter or longer periods of repose. The basalt beds are separated by sedimentary layers. Earthquakes are a consequence of accumulated strain to which the crust suddenly yields. All this indicates that the crust of the Earth does not immediately accomodate itself to the forces, but that it yields first when the steadily increasing strain has reached a certain point. It appears, still further, to proceed from geological investigations, that there are periods in the history of the Earth when the changes occur on a larger scale than usual. In his Textbook previously mentioned (p. 197—198) *A. Geikie* speaks of the great eruptive masses, fissure eruptions, that have taken place, both in the Old and New Worlds, in which melted masses were projected from numerous rents and covered thousands of square miles. Modern volcanicity appears slight compared with those gigantic eruptions.

We will now pass on to examine whether these changes in the form of the Earth may possibly stand in any relation to the periodical change in the eccentricity of the orbit.

We begin with the assumption that *Thomson* and *Tait* speak correctly, when they state that the tidal-wave is the most important of the forces, that contribute to alter the length of the sidereal day. But along with the oceanic tidal-wave acts the internal friction, „the bodily tides“ assumed by *Darwin*. Both are of course dependent on the lunar and solar distance, and we must therefore investigate whether the tidal action of these bodies on the Earth changes with the eccentricity of the Earth's orbit. It proceeds from *Darwin's* investigations that the lunar tides in ancient times, long passed away, must have been much greater than now. I pass that bye, because that period lies so far back, and because the profiles, to be subsequently fitted into the curve of the eccentricity of the Earth's orbit, date from a late period, geologically speaking. As I thought that the dependence of the tidal wave on the eccentricity might, perhaps, have some geological importance, I consulted *H. Geelmuyden*, of the University Observatory, who with his usual kindness has given the following reply:

„The effect of the eccentricity (e) of the Earth's orbit upon the force that produces flood and ebb, and which for shortness' sake I will call tidal-force, is as follows: If r is the Sun's distance, then the solar tidal-force $P = \frac{C}{r^3}$, in which equation C contains the Sun's mass and the terrestrial radius. In the course of the year r varies, but the mean value of $\frac{1}{r^3}$ is found by an easy integration to be $\frac{1}{a^3 (1 - e^2)^{\frac{3}{2}}}$ where a is the constant mean distance. Consequently, the annual mean value of the solar tidal-force is:

$$P = \frac{C}{a^3 (1 - e^2)^{\frac{3}{2}}} = \frac{C}{a^3} (1 + {}^3/_2\, e^2 + \ldots)$$

From this it follows, that when the eccentricity increases, then the tidal-force also increases. If the increase in the first-named is $\triangle\, e$, and in the last-named $\triangle\, P$, then

$$\frac{\triangle\, P}{P} = \frac{3\, e \,.\, \triangle\, e}{1 - e^2} = 3\, e \,.\, \triangle\, e,$$

as $1 - e^2$ in the denominator is of no consequence.

At present $3\,e = {}^1/_{20}$ and $\triangle\, e = -\,0.00043$ per thousand years, consequently $3\,e \,.\, \triangle\, e = -\,0.00002$; or the solar tidal-force loses $\frac{1}{50000}$ of its value in every thousand years. When the eccentricity has attained it's greatest possible value, according to *Leverrier* 0.0667, then $e^2 = 0.00445$, ${}^3/_2\, e^2 = 0.00667$, consequently $P = 1.00667\, \frac{C}{a^3}$, or the difference between maximum and minimum is $\frac{1}{150}$ of the value.

The monthly mean value of the lunar tidal-force will, of course, in the same manner, be dependent on the eccentricity of the lunar orbit, but as this is subject to no particular secular variation it need not be taken into consideration. On the other hand the mean lunar distance is, in an extremely slight degree, it is true, dependent on the eccentricity of the Earth's orbit, in such manner that the lunar tidal-force becomes

$$P' = \frac{C_1}{a'^{\,3}} (1 - q \,.\, {}^3/_2\, e^2).$$

Consequently the eccentricity acts, here, in an opposite direction, therefore in such a way that the force diminishes as the eccentricity increases; but as the factor q by which ${}^3/_2\, e^2$ is multiplied, is only $\frac{3}{400}$; whilst the quantity outside the brackets $\frac{C'}{a'^3} = {}^5/_2 \cdot \frac{C}{a^3}$ (as the lunar force bears to the solar force, the ratio as 5 : 2 nearly); the effect on the tidal-wave is only $\frac{3}{400} \cdot \frac{5}{2} = \frac{1}{53}$ of the former."

We see then that the tidal-force rises and falls with the eccentricity of the Earht's orbit. It becomes altered to the extent of $\frac{1}{150}$ of its value from the greatest to the least eccentricity. This force is the most important in its effect on the day and causes it to become longer. The most important force in shortening the day is, according to *Thomson*, the cooling of the Earth, but he has estimated its effect at only $\frac{1}{6000}$ part of that of the tidal-force (and, here, attention is only paid to the oceanic tidal-wave). When, therefore, the tidal-force diminishes and increases with $\frac{1}{150}$ of its value, this periodical change is not balanced by forces acting in opposite direction, and we must therefore conclude that the sidereal day steadily becomes longer, but that the increase is periodically greater and lesser. It increases in length, quicker and quicker, as long as the eccentricity of the Earth's orbit increases, and slower and slower, as long as the eccentricity diminishes; in other words, the centrifugal force diminishes, and the equatorial regions increase in weight, quicker and quicker, during increasing, and slower and slower during decreasing eccentricity.

There prevails, even among physicists, as previously stated, a difference of opinion as to whether the Earth will change its form, in the event of change in the centrifugal force. *Thomson* is most disposed to believe that it will not, *Darwin* thinks that it will. And among other physicists, with whom I have consulted, there prevails a similar difference of opinion in relation to this subject. One thinks that even several hours lengthening of the day would be insufficient to alter the form of the solid Earth; another thinks that the solid Earth would perhaps alter its form with as much ease as the sea. And as to the speed with which the sidereal day becomes prolonged there are quite as greatly divided opinions. *Darwin* assumes many times as great changes as *Thomson* does. It is clear, therefore, that these problems can scarcely yet be finally solved, and that different hypotheses may still be discussed. We will choose the one, then, that best explains the facts, whilst we assume that the variation of the tidal-wave with the eccentricity of the Earth's orbit may possibly be the cause of the periodical displacement of the beach-lines. But we present this hypothesis with every possible reservation. The different opinions held by the most eminent physicists on these subjects, and the beautiful manner in which the hypothesis is supported by so many facts, alone gives us courage to express hypotheses that, probably by many, will be considered to be not only bold but even improbable.

The motive force of the alterations in the form of the Earth therefore varies periodically with the eccentricity of the terrestrial orbit. The seas being fluid accommodate themselves, instantly, to the slightest alteration in the length of the day, whilst the solid crust opposes a resistance. The day becomes lengthened slowly and imperceptibly. The influence of weak forces, we have seen above, is also dependent on the length of the time in which they act. Even weak forces may therefore exercise an influence, if they only have sufficient time to act in. It is, therefore, probable that the dry land will be more sluggish in its movement than the waters. There will elapse some time ere the „crust“ and the internal plastic mass will begin to yield. The foundation of a building begins often, first to give way after the building has stood for some time. If, now, the solid Earth is slower in its movements than the sea, and the movements of both the sea and the land take place periodically, with greater and lesser force, because the motive force is stronger or weaker according as the eccentricity of the orbit rises or falls; it becomes quite imaginable that the beach-lines will come to be displaced and oscillate up and down once, for every time the eccentricity rises and falls; moreover there must be the greatest probability that the solid crust, at one or other point, must yield when the strain in the interior increases most rapidly.

It becomes necessary now to investigate whether the action of the tidal-wave and the alteration in its force is sufficiently great to explain the displacement of the beach-lines. This problem belongs to the science of physical mathematics, and it is not in my line to solve it. I present it as a question to be solved by competent authorities, and restrict myself to the following remarks.

If the sidereal day was at one time several hours shorter, and the Earth at that period was a solid body, the strain and pressure in the interior would rise with the length of the day until, at last, the strain would be so great that the Earth would begin to yield. It would then accommodate itself, if not entirely, still partially, until the strain was at all events partially relieved. Probably, then, a pause would occur in which fresh strain would accumulate, to produce a new change of form; and these paroxysmal alterations of form, in the body of the Earth, which is strained to its limit of elasticity, probably would take place, when the eccentricity had attained it's highest value, and the strain had increased most rapidly, or at some short time afterwards. In such circumstances, probably, the slight change which the tidal-wave is subjected to on account of the varying eccentricity, may turn the scale and be decisive for the time of the dry land's changes.

Thomson states (Transact. Geol. Soc., Glasgow 1868) that it is still hopeless to attempt to solve the problem of how speedily the sidereal day becomes lengthened by reason of tidal action. Experimentally, he calculates (l. c. p. 26) the effect of the present tidal-wave to be so great, that the Earth will in 100 years be retarded 180 seconds, corresponding to a prolongation of the sidereal day of 0.01 second, and if, for the sake of simplicity, the retarding force is assumed to be constant, the day would thus, at the expiry of 100,000 years (the time that on the average is necessary for an oscillation of the eccentricity), have become 10 seconds longer; and *Thomson* speaks only of the ocean's tidal-wave. To this force Darwin's „internal tide“, his „bodily tides“, should now be added, but which I have no means of calculating.

Many millions of years ago, when the Moon was nearer, and the tidal-force much greater, the length of the sidereal day also increased more rapidly. But now its increase is indubitably very slow; and for that reason we cannot expect any great general changes of level in a short time.

To an increase of 10 seconds in the length of the day there corresponds (according to *Todd* l. c.) a shortening of the equatorial radius by 5.6 m., and the double prolongation of the polar one, 11.2 m.

What value the lengthening of the day had, in reality, during the tertiary period we do not know. Much greater than in present times it can scarcely have been; and it appears, therefore, in any case, to result from what has been said above, that the vertical displacement of the beach-line during each oscillation can, *in general*, not have exceeded a few metres, if our attempt at explanation of the phenomenon is correct.

We must, therefore, investigate whether the displacement of the beach-lines was so very considerable.

We must, then, first investigate, how much there has been deposited in each period of precession, and the thickness of the strata of every stage. The thickness of the beds depends, first and foremost, upon the locality of the place, whether it lay close to or distant from land or the estuaries of rivers, and upon the nature of the layers; chemical precipitations are usually less thick than mechanical ones. As a mean for each synodical period of precession (20—21000 years) I have found the following values for the various alternations of strata:

Marl and silicate of lime from	0.6—2.2	m.
Clay and silicate of lime	1.3	„
Marl, gypsum, silicate of lime, marine . . .	1.3—1.4	„
The same, fresh-water	2.8—2.9	„
Lime and marl	1.8—2.5	„
Marl, argillaceous lime-stone, ironstone, sandy marl	2.0	„

Sand, calcareous sandstone, marine	2.0—2.3 m.
The same, fresh-water	3.0 „
Sand, clay, ironstone, marine	5.0—6 0 „
Clay, limestone, iron-sandstone	5.0—7.0 „
Sand, marls, iron-sandstone, lignite	30 — 60 „

In each stage there are usually, when there has only been one oscillation of the sea, 4—5 such alternations, so that the thickness of the stages is only small as a rule. I will give the following examples. First from the Basin of Paris: Calcaire grossier, which represents 25 alternations, and several, 5—6 oscillations, is only 31.5 m. in thickness; sables de Beauchamp 13—14 m.; Calcaire de St. Ouen, having 10 alternations, is only 6—7 m. in thickness; gypse marin 16—17 m.; gypse palustre 20 m.; sable d'Etampes 11—12 m. The beds of the Isle of Wight are thicker, but also richer in mechanical deposits: Plastic clay 26 m.; London clay 61 m.; Lower Bagshot (sand, clay, lignite, iron-sandstone, 7 alternations) as much as 200 m.; Bracklesham of same description as the last, but without any alternation 33.5 m.; Middle Bagshot 91 m.; Upper Bagshot (sand without alternation) 37 m.; Lower Headon 21 m.; Middle Headon 7 m. and Upper Headon 26 m.; The Osborne stage 19 m.; Bembridge limestone 7.6 m.; Bembridge marl 23 m.; The Hempstead stage 52 m. From Belgium we have the following thicknesses stated: Montian (coarse limestone, containing foraminifera) 93 m.; Heersian 32 m.; Landenian about 60 m.; Yprésian 140 m.; Bruxellian 50 m.; Lækenian 10 m.; Wemmelian up to 80 m. (only arrived at by boring); Tongrian 21 m.; Rupelian 60 m.; Anversian 3—4 m. (but near Utrecht 130 m. in an Artesian well). The thicknesses in the Basin of the Maine are as follows: Alzeyersand 50 m.; The septaria clay 50 m.; Elsheimersand 60 m.; Cyrena marl 40 m.; Cerithium limestone 25 m.; Corbicula limestone 25 m.; Litorinella clay 20 m. From Italy, *Seguenza* states the following thicknesses: Bartonian (partly conglomerates and probably several oscillations) 300 m.; Tongrian 50 m.; Langhian, Astian and Saharian each 200 m.; Zanclean 300 m. The Swiss Molasse (where it exists as a beach formation) is so thick that it forms entire mountains, but the Aquitanian at Bormida in Liguria has, according to *Charles Mayer-Eymar*, a still greater and perfectly unique thickness. Here, there is found (probably originally dipping) freshwater, with superimposed marine beach-formations having many alternations of sandstone and slate, whose thickness has not been accurately measured, but is supposed to be 3000 m. and the whole is supposed to have been formed in the Aquitanian age. And the same stage has a similar thickness in Bavaria, according to *Gümbel.* Mount Etna (12000 feet) is built up from volcanic eruptions in the latest geological ages, and after the Mediterranean had got a fauna resembling, in most respects, that of modern times.

The Mediterranean regions, with their great volcanicity, have (according to *Suess* and *Neumayr*) distinguished themselves by very considerable displacements of the crust of the Earth. The Aegean Sea and the Adriatic Sea have been formed by subsidences occurring in the latest geological ages. Under such conditions thick layers must have been formed near land in a short time. Eocene marine layers have been upheaved in folded chains 21000 feet above the sea, e. g. in Upper Asia. But all these are merely local revolutions. If we, on the other hand, look at those regions where the relations have been more slowly developed, we find, as seen from what has been said above, that the stages have only a small thickness. The layers of which they consist are partly fresh-water formations, partly formations from the shallow sea; there are no distinguished deep-water formations among them. They are in a great measure, probably for the greater part, formed in inland seas and bays, in basins that have been cut off from the Ocean by embankments. This we may conclude from the circumstance that salt-water and fresh-water formations so frequently alternate in the tertiary layers; because only when the sedimentation takes place in basin-shaped hollows can fresh-water basins be formed every time the sea retreats.

And if we have deep basins which are separated by embankments from the great ocean, a rise or fall of only a few metres in the beach-line will be sufficient to cover or drain the bank.

The deep basin would then alternately become salt and fresh. Thus, a rise of the ocean of a few metres would be sufficient to lead to the formation of thick salt-water layers in the basin. If the embankment now, again, becomes upheaved a few metres the basin will become fresh, and thick fresh-water layers may be superimposed the salt-water ones. And in this way the formation of alternating salt- and fresh-water layers may proceed, with slight displacements of the beach-line, until the basin is filled up.

It would appear to be more difficult to accommodate the hypothesis, with the quite considerable upheavals which some countries have undergone in the interval that has passed since the glacial age. Thus, the highest marine terraces, from the post-glacial age, are, near Christiania and Throndhjem, situated 188 metres above the sea. But in other parts of our country the highest marine terraces are situated much lower, so that it looks as if the upheaval had not been uniformly great in all parts. It appears to have been less, outwards from the centre of the land. And in Southern Sweden and Denmark it has in the same period been inconsiderable. *Penck* has (Schwankungen des Meeresspiegels in Jahrb. d. Geogr. Gesellsch., München VII) shown that an inland glacial mass exerts an attraction on the sea, which on that account stands higher on the coasts of a country which is covered by ice. The melting of the inland ice must, thus, have caused the seas on our coast to have sunk a little, but the difference between the situations of the highest marine terraces in the various parts of Scandinavia is far too great[1], even in adjoining districts, to permit of an explanation in this manner, and the most likely explanation is, that the land has been upheaved in different degrees[2] in different places. It is also a probable assumption that the crust has not everywhere the same power of resistance to the inward strain, and that the plastic mass must be forced upwards, especially, under the more yielding parts of the upper surface. We meet with a striking instance of this in the Laccolites of North America. The erupted matters are here pressed upwards from the deep, and have upheaved the beds into a cupolar vault, in such a way that the upheaval has varied in degree in the different parts, and is greatest in the middle of the cupola. We may suppose that similar forces, although it may be on a much greater scale, have contributed to the upheaval of Scandinavia, that Scandinavia is, *sit venia verbo*, like a laccolite on a gigantic scale. We must, besides, remember that the alterations in the surface of the Earth, that have taken place in the tertiary and quarternary periods, however great they may to our vision appear to be, are yet slight in proportion to the whole terrestrial mass; and small forces acting on a great mass may produce quite considerable local effects, in the event of the changes not taking place everywhere on the same scale. If we suppose that the upheaval has, in this manner, not everywhere been equally great, then a lowering of the equatorial belt, of only a couple of metres, would be sufficient to cause many such countries as Scandinavia to be upheaved many metres, and there would still remain reserves of force not expended or exhausted.

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[1] Vide *E. von Drygalski:* Die Geoiddeformationen der Eiszeit (Zeitschrift d. Ges. für Erdkunde in Berlin. XXII. Berlin 1887, p. 169 ff.).

[2] A similar irregular upheaval has doubtless also taken place in ancient periods of upheaval. The Bergen conglomerate layers, the old slates, lie on a higher level the farther from the coast we go inland (vide *Kjerulf*: Udsigt over det sydl. Norges Geologi. Christiania 1879, p. 154—156 etc. and *Helland* in Arch. f. Math. o. Naturv. Bind VI. Christiania 1881, p. 222).

It is of course not asserted that Scandinavia must be upheaved, always to the same extent every time the eccentricity has attained a high value. If the upheaval has been great in a given time, it is likely that the ensuing period of upheaval will have more difficulty in elevating the already previously upheaved land. The situation of the weakest points will change. Next time the upheaval will perhaps preferably act in other regions. If we consider the tertiary formations of Europe we find that the series of layers is nowhere complete. Only when we combine all the layers formed at different places do we obtain a complete profile. The reason of this is, certainly, partly owing to the changes in the form of the Earth not having taken place everywhere at the same time. The great eccentricities caused upheavals in different places at different times. Finally, there is an important circumstance which must here be pointed out, and which shows how quietly the oscillations took place under normal conditions. Although, therefore, according to our assumption, the radii of the higher latitudes become steadily lengthened, and those of lower latitudes shortened, yet the beach-lines during long geological periods return in the course of the oscillations, in many places, to the former old situation. Thus, *A. de Lapparent* says (Bull. Soc. Géol. de France ser. III, vol. XV, p. 400): „J'ai signalé, dans le Cotentin, une concordance entre les rivages actuels et ceux ou s'arrêtait la mer à diverses epoques de l'historie géologique. J'y ai montré les lignes de rivage se reproduisant, presque sans variations d'altitude, aux epoques hetangienne, sinémurienne, liassienne, cenomanienne, danienne, parisienne, tongrienne, pliocène et actuelle, ..., que huit ou neuf fois au moins, depuis l'ère primaire, la coincidence des rivages se s'est reproduite sur le même point;" and at the same place (p. 227) he says: „C'est seulement par dizaines de mètres que doivent se compter, dans les parages du Cotentin, les differences entre les nivaux successifs des mers depuis le Trias jusqu'à nos jours." Here we see that the changes in level have taken place with great regularity. The sea has risen and subsequently the land has risen; and these alternating risings have taken place with such regularity that the beach-line, again and again, at long intervals, has returned to its old position.

It appears from this that there is really a possibility of our hypothesis being sufficient to explain the displacements of the beach-lines that have occurred. We have up to the present considered the relations in the higher latitudes. In the lower latitudes the whole must sink. Here there must be formed „Horste", like what *Suess* has supposed, and in respect of those regions *Lapparent*'s criticism may perhaps not be quite warranted. He has attacked *Suess*'s doctrine of „Horste" in its entiriety, but has only specially criticized it in regard to such regions (Colorado, the Vosges, the Black Forest, the French Central Plateau) as are situated in the higher latitudes. The regions named are (cfr. *Lapparent*) upheaved more than the surroundings, which also quite coincides with the views discussed above. But in lower latitudes, where a general sinking takes place in the course of time, the portions left undisturbed will form real „Horste“ of *Suess's* kind. And it is scarcely opposed to our hypothesis if we suppose, with *Suess*, that the Indian Ocean is formed by a sinking, and that Africa, Madagascar, Hindostan and several other lands are „Horste“, parts of the crust which have been left undisturbed, or which have sunk less than their surroundings. In these countries there appears, so far as their geology is yet known, to be only few marine formations belonging to the mesozoic and cainozoic eras.

I have said, above, that the different parts of the crust must be assumed to have different powers of resistance to the internal strain. We may conclude that, from the unevenness of the surface, and also from ancient, originally level, formations having been upheaved with great irregularity at different places. In other words, we have an unevenness of surface which cannot be accounted for only by the action of the erosive forces.

The alterations in the surface of the Earth really take place in very different degree at different places. The greatest disturbances are to be found in the folded mountain ranges, and these we have belonging to all geological periods. It is worthy of notice that places where great folding took place in ancient times, appear, later, to have been left undisturbed by the folding process[1]; because above the abraded tops of old folds there lie, often, even old formations in undisturbed level position. The loftiest folded ranges of the Earth are, therefore, those where the folding has continued up to the latest times.[2] Along both coasts of the

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[1] If the terrestrial axis, which some Astronomers (e. g. *Gyldén*) suppose, can, in the course of time, change its position, the direction of the strains produced by the lengthening of the sidereal day will become altered, and the situation of the parts of the crust exposed to the greatest strain will change.

[2] The following review is derived from *Suess's* interesting studies in his great work „Antlitz der Erde“.

Pacific Ocean, from Cape Horn to the Aleutian Islands, and downwards along the east coast of Asia to the Sunda islands, immense ranges extend, accompanied by series of volcanoes; and from the Himalayas through the Caucasus, the Balkans, the Alps to the Pyrenees, and Mount Atlas, there extend, frequently through volcanic regions, a similar series of immense ranges. These, the loftiest mountains of the Earth, are also its youngest; they have as yet suffered least from the tooth of time.

But those strongly folded regions are of only slight extent in proportion to the rest of the surface of the Earth. On both sides of these folds there lie great plateaux and lowlands, quite, or nearly so, without folds, and altogether with undisturbed level layers. These are *Suess's* tables (Tafeln): Africa, Western North America (in the Eastern we have no foldings younger than from the coal period), Brazils, Australia, Arabia, Persia, India, Siberia, Russia, and similar tables, where the crust is much less disturbed. Without doubt the same is the case in regard to the sea-bottoms, at any rate in respect of most of them.

When the sidereal day becomes lengthened the sea accommodates itself immediately to the change. It sinks in lower latitudes and rises in the higher ones. According as the internal strain on the crust rises towards the poles, the resistance of the sea-bottom in the same regions also rises, because the sea rises. But the portions not covered by sea are only exposed to the increasing internal pressure, without any external resistance being created. And in the lower latitudes the process is the same. According as the crust increases in weight the sea sinks, and the internal strain rises more rapidly on the continents where nothing is removed, than in the sea where the column of water sinks. Therefore I believe that the continents are weaker points. The movements of the sea diminish the effect of the decreasing centrifugal force, in all places covered by sea, but the strain acts with undiminished force everywhere on the dry surface of the earth, both in lower and higher latitudes.

Whatever the cause originally may have been, that has decided the division of land and sea upon our Globe, it is, it appears to me, reasonable to suppose, that the movement of the sea is a conservative force, that probably has contributed to the continents and the oceans having, upon the whole, retained their great divisions from the oldest times up to now.

There is, thus, reason to believe that the dry lands yield with greater facility than the seabottom, and that they easier, than it, may rise and fall. And they are also divided from the ocean depths by lines rich in volcanoes, where the connection between the portions of the crust appear to be weaker than elsewhere. The folding process, it may well be, perhaps, is even a consequence of the movements of the tables on each side not being alike.

But the margin between the ocean depths and the base of the continents does not always coincide with the present coastline. Along the coast there are often shallow stretches in the ocean. These are the bases of continents, covered by the seas; and first at a certain distance from the coast do the great ocean depths appear.

The Trias period has been so named, because it shows a distinct triple division. It begins with fresh-water and littoral formations; above these come formations from the deeper seas, and these, again, are superimposed by fresh-water and littoral formations. When it first commenced, the continents lay high in relation to the sea; as it proceeded the sea rose higher and higher, then the land began again to rise, and when the period closed, the land again lay high in relation to the sea. And these great changes in the position of the beach-line were completed, indubitably, in the course of many lesser oscillations.

But in the same manner as in the Trias, do similar relations exist, also, in other geological formations. They begin with beach-formations (frequently a conglomerate lies at the bottom); after that follow deeper-sea-formations, and, finally, come other beach formations. The term Trias suits well, therefore, in reality, for them all. The first who has called attention to this remarkable triple division of the formations is, so far as I know, *Eaton*. Subsequently, it has been treated of by *J. S. Newberry* in his Memoir: Circles of Deposition in American Sedimentary Rocks (Proceed. Amer. Assoc. 1873, vol. XXII, p. 185), *Hull* (Transact. Geol. Soc. Glasgow, 1868, III, part 1, p. 39); *vide* also *A. Geikie's* Textbook of Geology, p. 498, where still further references to the literature of the subject may be found. *Principal Dawson* calls those periods „cycles" and he gives in his „Story of the Earth and Man" the following cycles of this kind: 1) Cambrian, 2) Lower Silurian, 3) Upper Silurian, 4) Devonian, 5) Carboniferous, 6) Permian, 7) Triassic, 8) Lower Jurassic, 9) Middle Jurassic, 10) Upper Jurassic, 11) Cretaceous and 12) Tertiary.[1] It is seen therefore that those cycles are periods of long duration: each of them has certainly lasted for hundreds of thousands of years; and in the middle of each of the cycles the great transgressions of the seas have reached their maximum point. The cycles are separated by continental periods. During the upheaval of the dry land the position of the level beds became frequently disturbed, causing the beds of the new cycle to lie unconformably on the top of the older one.

The development has in that manner proceeded, at any rate in the northern hemisphere. *Mojsisowics*, *Suess* and others have laid stress on the fact that it has proceeded at the same time, in one direction both in Europe, Asia and North America. These great changes have taken place over the entire Northern Hemisphere, and they have always had the same direction on both sides of the oceans. And the same geologists have rightly accentuated that this law is one of the most remarkable results of geological investigation.

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[1] As we shall subsequently see, this formation contains two cycles.

The development of organic life has, as we now know, gone on uninterruptedly from the remotest times. There has never been any destruction of all the old life, never any complete new creation. The new forms have developed themselves from the old, through transition-stages and through millions of years. If one knew all the beds that have formed themselves it would become impossible to draw any line between geological formations. The one would imperceptibly pass into the other.

The margin between the formations corresponds to great gaps in the series of layers. In the period that separated the youngest bed in an older, and the oldest bed of a later cycle, the continents of the northern hemisphere lay so high that marine beds were not formed in those parts of the crust of the earth which are accessible for our investigations. Meanwhile the development of the various forms of life proceeded in their usual course. But when the land, after a long time, was again flooded the animal life of the seas had become changed, and beds containing new fossils were superimposed the old ones. And it is in accordance with the animal remains in the marine beds that the formations are established. Thus, the sudden alteration of fossils where a new formation begins is not dependent on any catastrophe, but simply upon shorter or longer interruption in the sedimentation in those parts of the earth which we can investigate. There is no doubt that the transition-layers between the formations are to be found, but they lie hidden from our view at the bottom of the sea. Only in a few especially folded ranges are those layers upheaved, and thus capable of being investigated. Thus in the Alps are found transition layers between Cretaceous and Tertiary, between Permian and Trias etc.[1]

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[1] „As long ago as 1846, *Darwin*, in his observations in South America, showed that certain assemblages of fossils presented a blending of characters, which are of Jurassic and Cretaceous age, respectively. Since that date, the study of the fossil faunas of South Africa, India, Australia, New Zealand, and the Western Territories of North America has furnished an abundance of facts of the same kind, showing that no classification of geological periods can possibly be of worldwide application“ (*J. W. Judd,* in Nature I March 1888, p. 426). Vide also *Mojsisowicz:* Die Dolomitriffe Südtirols und

If we were to attempt to establish geological formations with the aid afforded by remains of land animals and land plants, the borders of these would not coincide with the borders established by an investigation of the marine fauna.[1] To name an instance, the appearance of dicotyledons does not coincide with any formation's limit, but they appear first in the upper Cretaceous formation in a multitude of forms.

We know from the Tertiary period, when we disregard the layers of the great mountain ranges, only formations from the shallow seas. The Tertiary layers that correspond to the deeper seaformations of the older periods, and which, without their formation being interrupted by the numerous slight oscillations of the beach lines, were deposited farther from land in those periods, still, for the greater part lie concealed from our vision in the depths of the seas.

Terrestrial formations, fresh-water and coast formations, such as we find in abundance in our Tertiary basins, are specially exposed to destroying influences; because they are more frequently upheaved over the protecting waters. In the ancient cycles such formations are more rare, probably, in a great measure, for the reason that they have been destroyed by denudation. We must therefore conclude that the formations of the Tertiary period would resemble those of the ancient cycles far more, if our knowledge of them was equally great. From the ancient cycles we frequently recognize, especially, deeper sea formations, whilst from the younger cycles we recognize formations, principally, from the shallow seas or fresh-water. In a distant future the Tertiary formations, then remaining visible, will come to resemble those now left visible from the more ancient cycles.

Venetiens. Vienna 1879, p. 36, and v. *Hauer:* Die Geologie. Vienna 1875, p. 515.

[1] „The growth of our knowledge concerning the terrestrial faunas and floras of ancient geological periods, has constantly forced upon the minds of many geologists the necessity of a duplicate classification of geological periods, based on the study of marine and terrestrial organisms respectively" (*J. W. Judd* in Nature 1 March 1888, p. 427).

Dawson expresses the thought (l. c. p. 176—179) that the remarkable regularity, with wich these cycles return, may perhaps be owing to a cosmic cause, and be dependent on one or other astronomical period. But he appears to reject that idea subsequently, because the Palæozoic cycles have layers that are 4—5 times as thick as the Mesozoic (l. c. p. 195). We might therefore suppose that a longer time must have been necessary for their formation. But he accentuates, on the other side, that in the Palæozoic period the changes in the organic world took place more slowly, in relation to the formation of beds, than subsequently, so that the fossils extend through greater thicknesses than in the less thick later cycles. If I were to draw a conclusion from these facts cited by *Dawson*, I would arrive at a different result from him. I would consider it reasonable to assume that the formation of beds in the Palæozoic epoch proceeded more rapidly than afterwards. If the Moon was at that time closer to us and the sidereal day shorter, as *Darwin* has supposed, the tidal-wave must have been both stronger, and have acted more frequently than now. The coast would be destroyed far quicker, and the sea would obtain much more stuff to precipitate. A cycle of that time would have a greater thickness of layers than a later and younger one, and the fossils would extend through a greater thickness of bed than in the latter. I see, at present, no reasonable ground for supposing that the development of new species would be accelerated in the same degree as the formation of beds.

There is, therefore, reason for supposing that it is these changes in the Earth's form, occurring at long intervals, that enables us to distinguish between geological formations. But such great changes in the divisions of land and seas must, of necessity, produce also considerable changes of climate, and along with that, surely enough, changes also in the forms of animal and vegetable life. In one of my previous Papers I have already proposed the view that the glacial epoch was caused by a change in the division of land and seas. If the land obtained a great distribution in the middle and higher latitudes, especially if tongues of land were formed across the ocean like the ancient supposed bridge of land in the line of the Faröe Islands and Iceland, from Scotland to Greenland; the warm ocean currents would be shut out from the higher latitudes. The Northern seas would then become seas of ice, and, when the snowfall was sufficient, inland ice would be formed. In a Memoir: Natürliche Warmwasserheizung als Princip der klimatischen Zustände der geologischen Formationen (in Abh. Senckenb. Ges. Frankf. a. M. Vol. XIII, 1884 p. 277 ff.) *J. Probst* has, like *Sartorius von Waltershausen* (Untersuchungen über die Klimate der Gegenwart und Vergangenheit 1865), rightly pointed out the great importance that warm ocean currents have, and have had, in tempering the climate of the higher latitudes.

It has been a general supposition among geologists that the animal and vegetable life of the ancient formations was much more uniform over the entire Globe than it is now. But that opinion must now be somewhat altered, in accordance with modern investigations. *J. W. Judd*, says for instance (Nature I March 1888, p. 424 ff.) in respect of the oldest beds containing fossils (the Cambrian): „Even at that early period there were life provinces with a distribution of organisms in space quite analogous to that which exists at the present day.“ Examples of geographical provinces are cited by him from the Silurian Triassic, Jurassic and Cretaceous periods; and he further states: „I believe that the study of fossils from remote parts of the earth's surface has abundantly substantiated Prof. *Huxley's* suggestion that geographical provinces and zones may have been as distinctly marked in the Palæozoic epoch as at present.“ Most of the beds of ancient times date from periods in which the land lay low in relation to the sea; and the difference between the geographical provinces is far less in the great ocean depths than near the coasts and on the interior land.

It has hitherto been an accepted doctrine, too, that the climate of ancient days was much milder and more uniform over the whole Earth than it is now. The farther back we go, it has been said, the warmer was it, and that phenomenon has been placed in connection with the interior heat of the earth. The Glacial age stood as an interruption in the continuity of this steady cooling process. In the times of transgression, when the land lay low, and the seas were widely distributed in northern latitudes, the warm ocean currents had much easier access to the Poles than in the dry-land or continental periods. As we, however, are best acquainted with the beds formed in the times of transgression, and as the beds of the continental periods are, for the greater part, destroyed by denudation and, partly, are concealed by the waters; it is reasonable enough that the beds of the ancient cycles must show less distinct geographical provinces, and, as a rule, testify to milder climate, even in high latitudes. But the great alterations in the division of land and sea have compelled us to assume that, step by step, with these alterations, a periodical alteration of climate has also taken place, which has been far greater and more radical than the alteration produced by the period of precession.

Ramsay, *Croll*, *J. Geikie* and others have supposed that they had found, more or less certain traces of glacial ages in the ancient formations (vide e. g. *J. Geikie:* The Great Ice Age. Ed. 2. London 1877, Appendix p. 566 ff.).

Some of these traces appear to prove that at all events there must have been several other glacial ages than the posttertiary. But *v. Richthofen* (Führer für Forschungsreisende, p. 362) states that those presumable traces of glacial epochs are perhaps only an abrasional phenomenon, that the beating of the waves on the shore might form conglomerates with striated stones. Whatever the real facts may be in regard to some of those presumable ancient glacial ages, the most distinct and certain traces (cfr. *J. Geikie* l. c.) are seen to be obtained in the Devonian sandstone „Old Red“ of England and Scotland; from the commencement of the Carboniferous period (Scotland); from Permian conglomerate (England); from the Eocene epoch (Switzerland). The most speaking evidence (with striated stones) is obtained from the periods when the land was widely distributed.

In regard to these great transgressions, we must bear in mind that it is only in the folded ranges and in strongly upheaved regions (e. g. in the Alps, the Himalayas, Colorado etc.) that marine formed beds from the younger and youngest geological epochs are found at any particularly great height above the sea. Those great upheavals are, if we consider them in relation to the great whole, only to be regarded as quite local phenomena. When the beds were formed, they lay far lower down, and when we now find an alternation of marine beds and freshwater beds in such formations, we must guard ourselves against believing that the ocean rose and fell in relation to the land for thousands of feet at each oscillation. During the period of formation it was only necessary for the beach-line to have oscillated a few metres up and down. Afterwards the entire series of layers became upheaved, by locally acting subterranean forces, high above its original level.

Therefore, I think, that not even do the great transgressions imply, in any specially great degree, the displacement of beach-lines in a vertical direction. Where there are extensive lowlands, with basin-formed depressions, a slight rise may be quite sufficient to produce great geographical changes.

It is also possible that these transgressions may be due to alterations in the eccentricity of the Earth's orbit.

We will now proceed to test our hypothesis by a comparison of the astronomical periods with the geological series of beds.

The curve of the eccentricity of the Earth's orbit has been calculated according to *Leverrier's* formula by *J. Croll* (Climate and Time. London 1875, p. 312) for a period of four million years; three millions backwards, and one million forward from the present time. The curve has also been calculated by *Mc. Farland*, according to the same formulas (Am. Journ. of Science Ser. III Vol. XX. New Haven 1880, p. 105). His calculation extends 3,250,000 years backwards, and 1,250,000 years forward from now. He has made his calculations with shorter time-intervals than *Croll* (*Croll* 50,000 years intervals, *Mc. Farland* 10,000 years) but the difference in the intervals does not exert any particular influence in altering the form of the curve. *Mc. Farland* has, in the same place, calculated the curve, for the same period, by the more modern formulas of *Stockwell.* The two curves show, upon the whole, a similar line through the whole length of their course, yet, as regards the first half, *Leverrier's* curve falls somewhat farther back. *Stockwell's* formulas are considered to be more accurate than *Leverrier's.*

Both curves have been published by *Mc. Farland.* If we compare them with each other we obtain the following results:

1. The curves, with a single slight variation, coincide from the present day, for 1 million of years backwards.

2. If we omit the portion between 7′ and 8′ of *Leverrier's* curve, Leverrier's and Stockwell's curves coincide in all essential respects, also for the still more remote period, although the coincidence is not so perfect as it is in the last million of years. This is due to the fact that the formulas give less accurate results for the more ancient epochs; as the number of years is made use of as a factor in the formula, small errors in the values taken for the masses of the planets will be increased in relation to time, and the result be, consequently, less perfect.

3. A very striking circumstance appears from those calculations. *The curve repeats itself after the expiry of 1,450,000 years* when calculated according to Stockwell's formulas. In the period of $4^1/_2$ million years, for which *Mc. Farland* has calculated it, it repeats itself in this way, with striking regularity, a little more than 3 times. In each of these cycles there are 16 arcs of the curve. Thus the arcs which, in the accompanying table, I have denoted 1—16 correspond with 1′—16′ and 1″—16″.

Mr. *Geelmuyden* the Astronomer has, as the result of some calculations which he has made at my request, declared that the general *course* of the curve is likely to be sufficiently accurate, to be safely used as the base of geological speculations, and that the deformations of the curve, owing to error in the values of the masses used by *Stockwell*, are not likely to be considerable.

4. The *mean value of the eccentricity* is least at the limit between two cycles; it rises in the first and falls in the last portion of each cycle, and attains, thus, its greatest value at about the middle of the cycles. The value for the first and second of the calculated cycles and their divisions is, therefore, as follows:

Cycle I	÷ 3,250,000 —	2,720,000	years	0.0304
	÷ 2,720,000 —	2,150,000	—	0.0332
	÷ 2,150,000 —	1,810,000	—	0.0203
Cycle II	÷ 1,810,000 —	1,250,000	—	0.0247
	÷ 1,250,000 —	700,000	—	0.0340
	÷ 700,000 —	350,000	—	0.0280
Cycle III	÷ 350,000 —	modern days		0.0291

As now, therefore, according to our hypothesis, the level of the sea in higher latitudes will rise and fall with the eccentricity, it must, then, not only rise and fall for each arc in the curve, but „the mean sea-level“ for long periods must also rise and fall with the mean value of the eccentricity, and cycles like I and II ought therefore to correspond to two cycles in the geological series of beds. The limits between the cycles of the curve ought to correspond to the periods of denudation that separate the geological cycles, and the middle ought to correspond to the periods of transgression.

The correctness of the two hypotheses presented in my Memoir on Alternation of strata may, as already there stated, be tested, if the geological profiles are compared with the curve of the eccentricity of the terrestrial orbit. A first attempt was made at that time with the Upper Eocene and Oligocene layers of the Paris Basin.

Many difficulties are still met with in that work. First and foremost the calculation of the curve is in itself not absolutely to be depended on for the more ancient times. This difficulty is, however, to a certain extent, surmounted by the fact that the curve repeats itself, so that it is probably not of great importance.

Another difficulty is to find long and accurately described profiles free of gaps in the series of beds. Profile-surveys are not sufficient. Geologists frequently only indicate, that there are some, it may be a few or many alternations of strata, without definitely stating the number.

A third difficulty lies in the separation of the alternation which is owing to precession, and that based on other more temporary and local relations. Especially is this difficulty perceptible in shore formations, but it has proved to be less than I had at first supposed.

A fourth difficulty lies in deciding the number of oscillations of the beach-lines. The higher the spot was situated, the more rarely was it flooded; the deeper it lay the more rarely was it raised above the sea. And the movement of the solid crust of the Earth has, as might be supposed, not been everywhere so uniform as that of the sea.

A fifth dificulty lies in the finding of perfectly typical profiles of the stages produced by the oscillations. As the sea rose and fell slowly, the number of the marine alternations of strata would be less and that of land and fresh-water formations greater, the higher the place lay, and the shorter the time was in which it lay sunk in the sea during each oscillation. But this difficulty is only of importance when the continuous profiles are so short that they do not pass through several oscillations.

In the absence of longer, continuous and accurately traced out, profiles, I have first been obliged to decide the number of the oscillations of the beach-lines in the Tertiary and Quaternary periods. Each of these oscillations, of which there have been about 36 from the commencement of the Tertiary period until now, has, in places at time covered by the sea, caused an alternation of marine-formed beds with fresh-water or land formations. For every considerable oscillation of the beach-lines there is a corresponding geological stage. In these stages there is a certain number of alternations. Upon studying the literature on the Tertiary basins of Europe, I have, in that way, formed a combined profile which, in respect of the alternation of strata, is certainly not yet everywhere filled up, but which starts from the commencement of the Tertiary period and extends until our own day, and I will now pass on to describe it. The manner in which profiles can be compared with the curve and the correctness of the hypotheses be tested, is as follows. Each arc of the curve corresponds to one oscillation of the sea. For higher latitudes it is assumed that the beach line oscillates up and down with the curve. Such an oscillation I term a geological stage. Each arc must therefore have its corresponding oscillation or stage and in each stage there must be as many alternations of strata as there are periods of precession in the corresponding arc. When the eccentricity between two or more arcs only falls slightly, neighbouring arcs form mountains, as it were, with two to three small peaks. We therefore obtain „stages“ with several more oscillations and several more alternations of strata than usual. We shall see instances of that in what follows. We may draw a line, intersecting the curve of eccentricity, denoting the margin between salt and fresh-water formations. That line may be almost or quite level. Whether it is to be drawn high or low, depends on how elevated above the sea the place was, where the beds were formed when the formation of the beds took place. The higher it lay the higher must the line be drawn. The place may have been situated so high that it was never covered by the sea. In that case the line lies higher than the entire curve, and all the beds are fresh-water or land formations. Or the place may have been situated so low that it never reached above the surface of the sea. In that last case the line lies lower than the entire curve, and all the beds are marine formations. Or the line may intersect the curve. In that case the marine beds alternate with land and fresh-water ones. The first-named correspond to the arcs of the curve which extend above the line, and the last-named to those that lie below it. And if there are no gaps in the series of beds there will be as many alternations of strata in the marine, fresh-water, and land formations as there are periods of precession in the corresponding arcs of the curve.

To commence with I will take the profile obtained from the Basin of Paris[1], and will attempt to connect it with modern days. I shall then speak of the Lower and Middle portion of the Eocene epoch.

The section from the Basin of Paris taken at Méry-sur Oise (Bull. Soc. géol. Fr. 1878 p. 243 ff.) shows, in ascending order, the following oscillations and alternations of strata, and may, in respect of the continuous portion of it, be fitted into *Stockwell's* curve, in the manner that the numbers attached to the arcs show for each oscillation:

Sables de Cuise, marine.
Calcaire grossier, lower and middle, marine, with 7 alternations.
Calcaire grossier: Caillasses à Cerithium, 2 marine alternations, and between these a layer of fresh-water shells.
Calcaire grossier: Caillasses à Lucina, marine with 5 alternations.
Calcaire grossier: Caillasses à Cardium, marine, with 11 alternations. A gap in the series of beds.
Sables de Beauchamp, freshwater and marine, about 4 alternations. Arcs 14—15.
Calcaire de St. Ouen, arcs 15—2′: 4 freshwater alternations, above them a marine bed (the apex of arc 16) and then 6 freshwater alternations.
Gypsum, marine, about 11 alternations. Arcs 2′—4′.
Gypsum, palustrian, freshwater, about 6 alternations. Arc. 5′.
Green Marl (Marne verte) brackish, 2 alternations. Arc. 6′.
Calcaire de Brie, freshwater, 1 alternation. Between the arcs 6′ and 7′.

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[1] This section is reproduced in my Memoir on alternations of strata (Biol. Centralbl. l. c.) where it is shown how closely it corresponds with Leverrier's curve of the eccentricity.

Marl and Molasse, Sables de Fontenaye, marine, 3 alternations. Arc 7′.

Meulières de Montmorency, Calcaire de Beauce (p. p.), freshwater. Between the arcs 7′ and 8′.

There is only a single irregularity: the arc 16, whose apex ought to correspond to the marine bed in the middle of the Calcaire de St. Ouen, does not reach so high, that we could expect a covering by the sea. But the oscillation is yet, at any rate, indicated in Stockwell's curve, too, and the marine formation consists of a single layer, and is so little prominent that it has only lately been distinguished.

Another profile, from another situation, in the Basin of Paris (la Frette, Bull. Soc. Géol. Fr. 1876, p. 471 ff.) has the same number of alternations as the previous one, and extends from 13 to 2′. The marine layer at 16 has not been pointed out in this profile, otherwise the same oscillations are indicated.

The profile from Méry-sur-Oise has, altogether, 71 alternations of which 25 are in the Calcaire grossier. A great part of the calculated curve is therefore filled out, in respect of 37 alternations, without any gap in the series of beds. At arc 7′, the marine formations of the basin become closed. In the Miocene epoch volcanic eruptions took place in Auvergne.

These oscillations of the beach-line have not been confined to the Basin of Paris. The series of beds in the Basin of the Gironde; which, by means of the Atlantic Ocean only, seems to have been connected with the Basin of Paris; are (according to *Vasseur:* Ann. Sc. Géol. Vol. XIII, p. 398 ff.): the Tertiary formations begin with the middle Eocene, Nummulitic sand and coarse lime-stone, marine. After that, upheaval of the land and erosion. After that a rising of the sea took place: clay containing Ostrea cucullaris (arcs 14–15). Then an upheaval again: Calcaire lacustre de Plassac, and along with it Calc. saumâtre de Bégadan (16—1′). Then a fresh rising of the sea: Calcaire marin de St. Estèphe and Calcaires et Marnes à Anomia Girondica (2′—4′). Upheaval and erosion. Mollasse (freshwater) de Fronsadais (6′?). Sea rising: Calcaire à Astéries de Bourg (marine 7'). Upheaval: Calcaire lacustre de l'Agenais 1st level (between 7' and 8'). This is contemporaneous with the Calcaire de Beauce in the Paris Basin. In the Basin of the Gironde new oscillations follow, which are Miocene, viz. Faluns de Bazas marine 8'. Upheaval: Calcaire lacustre de l'Agenais, 2nd level (between 8' and 9'); faluns de Léognan et Merignac, marine (9'); the so-called Mollasse de l'Anjou, which is absent in the Gironde basin is, according to *Tournouër* (Ann. Sc. Géol., l. c. p. 62) younger than 9', but older than Gironde's faluns de Salles; both are marine, and indicate probably two oscillations (10', 11'). After that there no doubt followed another Miocene oscillation which has left traces in the Basin of the Loire, in the marine faluns de la Dixmerie (arc 12').

The Miocene epoch contained, thus, in France, 5 oscillations. I have, however, not been able to obtain detailed profiles of all those series of beds.

We pass now across to England. In Mem. Geol. Surv. Gr. Brit. 1856 we have accurate profiles of the Tertiary formations in the Isle of Wight (by *Forbes* and *Bristow*). The series of beds contains, passing from below upwards, the following oscillations and alternations of strata:

Plastic Clay (brackish?) 4 alternations.
London Clay, marine. At least 11 alternations.
Lower Bagshot, (partially?) freshwater, 7 alternations.
Middle Bagshot (Bracklesham and Barton), the first-named freshwater, the second marine, and with 5 alternations.
Upper Bagshot. No alternations.

This portion of the series of beds is, partly, older than the Calcaire grossier, and there is at least one, probably two gaps in it. The following series of beds is, on the contrary, continuous:

Lower Headon, freshwater, and brackish, 7—8 alternations (arc 13, and the first part of 14).
Middle Headon, marine, 1 alternation at 14.
Upper Headon, freshwater, and brackish, 5 alternations between arcs 14 and 15.

Osborne, freshwater, 8—10 alternations, between arcs 15 and 1′.

Bembridge Lime-stone, freshwater, 3 alternations, between arcs 1′ and 2′.

Bembridge Oyster-bed, marine, at least 1 alternation, at 2′.

Bembridge Marl, freshwater, 6 alternations, arcs 2′ and 3′.

Hempstead Marl, freshwater, and brackish, 3—4 alternations, 4′ or 5′?

Hempstead corbula beds, marine, incomplete at the top owing to denudation, 1 alternation, arc 6′?

The profiles of the various stages have been taken from different parts of the island that have lain on different levels. When we bear that in mind, the series may be fitted with the curve, and corresponds, at any rate, tolerably well to it.

The number of alternations of strata in the last continuous part of this series of beds is about the same as in the contemporaneous beds contained in the Paris basin, although the beds have nearly double the thickness, (80 m. in the Paris basin and 156 m. in the Isle of Wight).

With the marine layer of Hempstead, England's marine formations are interrupted, and first, again, in the Pliocene epoch do signs of fresh lowerings under the sea appear. The basalts and volcanic eruptions in Ireland and the Hebrides are doubtless, at any rate, partly, Miocene. The basalt veins extend in some places right across the whole of England, but the main eruptions were on the Western side, and they can be traced thence across the Faroe Islands right up to Iceland.

We will now see whether we can fill out the curve from 7′, where the continuous profile of the Paris basin finishes off, up till modern times. The uppermost bed of the Paris basin lies on the border between the Oligocene and the Miocene epochs. As was shown, above, the Miocene epoch in France contained 5 oscillations. In Siebenburg there are (cfr. *Koch* in Földtani Közlöny several places) 5 Miocene stages viz. the Koroder beds, the Kettösmezö beds, the Hidalmas beds, the Mezöseger beds and the Feleker beds. All these stages are marine. Even although they are not everywhere separated by fresh-water formations, as is the case with several, at least, of the French Faluns, still they must be supposed to correspond to 5 oscillations. In a deeper ocean the bottom will not easily be upheaved over the surface during low eccentricities, but yet the oscillations will act in producing changes of fauna and, also, frequently, changes in the nature of the beds.

The Miocene beds of the Vienna basin are divided into three main „stages": the first and second Mediterranean, and the Sarmatian. If we study the detailed profiles more closely, however, there appears, also here, to have been 5 oscillations. The first Mediterranean, shows, thus (cfr. *Suess* in Sitzber. d. Wiener Akad. math. natw. Cl. 1866), in ascending order, the following series of beds:

> The beds at Molt, with oyster shells (broken), at the top brown-coal (lignite), 4 alternations of strata, arc 8′. Is supposed by *Suess* to be from the same horizon as Faluns de Bazas.
>
> The beds at Loibersdorf, Gauderndorf and Eggenburg, marine, probably with 8 alternations, at least partly, younger than the beds at Molt (arcs 8′? and 9′).
>
> „Schlier" with gypsum, at the top terrestrial plants. *Suess* calls it „ein ersterbendes Meer", and even appears disposed to regard it as an independent stage. Alternations, but scarcely more than a couple. The final part of arc 9′.
>
> The beds at Grund, marine; to judge from *Suess's* profiles, with few (3—4) alternations. The fauna forms a transition from the first to the second Mediterranean stage, and those beds at Grund are viewed, in the present day, by several Vienna geologists, as representing an independent stage. Arc 10′.

After this followed the greatest deluge, the second Mediterranean stage (arc 11′), contemporary with the French Faluns de Salles. The sea then rose right up into the interior alpine Vienna basin. I have been unable to determine the number of alternations in this stage, and have only seen sections of littoral formations described.

Finally, the latest Miocene oscillation, the Sarmatian stage, arc 12′. In some places (e. g. Constantinople) this stage begins with freshwater formations which are covered by marine ones (cfr. *Suess* Antlitz der Erde. I. p. 419). From a profile taken in Hungary (by *Peters* in Sitzber. d. Wien. Akad. math. natv. Cl. 1861), the stage has 4 alternations.

After that stage follow the Pliocene Congerian beds, which in the Vienna basin, are only represented by brackish-water formations, according to *Fuchs* (Jahrb. d. K. K. geol. Reichsanst. 1875) with 4 alternations; arc 13′. And with these beds the marine formations of the Vienna basin, Hungary, and Siebenburg are closed. Volcanic eruptions in those regions began already in the Oligocene epoch; they became most frequent in the Miocene, and in that epoch the Alps increased to great heights.

In the Mayence basin, after Oligocene beds (marine sand of Weinheim and septaria-clay) a fresh-water formation first follows; then the Miocene epoch began with a rising of the sea. But during volcanic eruptions the basin was upheaved and became more and more fresh. A continuous formation of beds took place. Above the Cerithium lime-stone, the Corbicula limestone and the Litorinella clay became deposited, with altogether 20 alternations, or somewhat more (cfr. *Lepsius:* Das Mainzerbecken). All those layers are Miocene.

We pass now further on in time. The Pliocene has four oscillations 13′, 14′, 15′ and 16′. We have already mentioned the Congerian beds of the Vienna basin. In England there are three oscillations: Coralline Crag (14′), Red Crag (15′) and Cromer clay or Westleton Shingle (16′). Profiles of these are to be found in the Quart. Journ. Geol. Soc. London 1871 (by *Prestwich*). The climate of Europe began to be colder in the Pliocene epoch. Already the oldest Pliocene beds in England contain stones that must have been transported by ice, and towards the close of the Pliocene epoch great glaciers were already formed; after the Pliocene comes the Glacial age. We have seen, how, during strong and widely spread volcanic eruptions, previously marine basins were, in the Oligocene, and especially in the Miocene epochs, upheaved over the surface of the sea, not, subsequently, to sink below it again (Paris, Vienna, Hungary, the Mayence basin, we might add Switzerland). We have seen how the Alps were upheaved in the Miocene epoch. The Faroe islands and Iceland were, at all events, built up of basalts and lavas, in a material degree, at the same period; perhaps even the submarine bank which connects Europe with Greenland was upheaved during the last part of the Miocene epoch or at the beginning of the Pliocene. In the Mediterranean the beach-lines, according to *Neumayr* (vide *Suess* Antl. d. Erde. I, p. 425) lay even lower at the beginning of the Pliocene epoch than in modern times. Without doubt all these risings must have had a great influence on the climate. The changes in the length of the sidereal day are dependent on the changes in the eccentricity. Geographical changes follow from the increase in the length of the day. And climate changes with the geographical conditions.

Coralline Crag in England has (cfr. *Prestwich)* only a thickness of 25 m. and cannot have many alternations. After that stage was formed, the land was upheaved, but thereupon was again partially lowered under the surface of the sea. During this lowering the Red Crag with Chillesford clay was deposited. Ledges were cut along the sea margin in the Coralline Crag, two above each other, and the beds of the new stage, partly, lie on the old shore-platforms. Red Crag is less thick than Coralline Crag and cannot contain many alternations.

In Belgium, also, we have two Pliocene stages that correspond to England's two crag-stages: the Anversian and the Scaldisian showing two oscillations.

To those two oscillations of the North Sea correspond two contemporary ones of the Mediterranean. *Suess* calls them the third and fourth Mediterranean stages. And already in the oldest division of the Pliocene epoch, the fauna of the Mediterranean indicates the existence of a somewhat colder climate *(Suess* Antl. d. Erde, I, p. 431).

Italy has thick Pliocene formations. *Seguenza* describes beds from that epoch 5—600 m. in thickness. I have been unable to obtain detailed profiles of those beds. To a certain extent they are conglomerates and littoral formations, like the thick Miocene Mollasse of Switzerland; and near the shore thick beds may be formed in a short time.

Profiles from Roussillon (by *Depéret* in Ann. Sc. géol., vol. XVII, 1885) show 4 alternations in the stage contemporary with the Coralline crag (arc 14'). The superimposed stage is, in Rousillon, a fresh-water formation. The land was upheaved. The fresh-water stage contains several alternations, probably 6—8, so far as I can gather from the profiles, which are not quite precisely described (arcs 15'—16').

We turn again to England. The fossils of the Red Crag show the existence of a colder climate than those of the Coralline Crag do, and the Chillesford beds, pertaining to the latest portion of Red Crag, contain purely arctic shells. The Glacial age is advancing. After the formation of the Red Crag, England was upheaved again and became land-bound to the Continent. Extinct mammalia wandered in the forests which were formed of now-existing trees (spruce, pine and the like), showing, thus, a temperate climate, milder than that of the Chillesford beds, and about the same as now. „The forest bed of Cromer“ became covered by marine layers, Westleton shingle and Cromer clay (arc 16'). In the latest Pliocene land-formations at Cromer, *Nathorst* has discovered arctic plants (Salix polaris and others), and Cromer clay indicates the proximity of inland ice· With this the Pliocene epoch closes.

In regard to the Quaternary oscillations we will take the beds in England, as they are described by *J. Geikie* (Great Ice Age ed. 2. p. 387 ff.), as our guide.

The Quaternary epoch begins with retreatment of the ice and a considerable denudation. After that the sea rose again and covered large parts of Eastern England. Then, again, the inland ice increased and formed a bottom-moraine, the great chalky boulder-clay (arc 1''). After that ice-age an upheaval of the land seems to have taken place, and the ice retreated. But a new rising of the sea followed (Bridlington Crag) and a new ice-age (purple boulder-clay, arc 2″). A new upheaval seems to have followed, with a new interglacial epoch. Then came a third rise of the sea, which was very considerable, and which, in Wales, at Moel Tryfaen, at Macclesfield and in Ireland, has left marine shells at heights almost approaching to those in which the old Norwegian „seter“ or beach-lines in Österdalen, Læsje etc. are found 1000—1300 feet above the sea.

Like the previously mentioned inundations, this was also followed by a glacial age, the last, Hessle boulder-clay (arc 3″). And finally the land was upheaved and the ice melted. The Post-glacial age, with its 4 beds of peat (the final part of 3″ and 4″) arrived. A slight oscillation of the sea immediately preceding the present time corresponds to the arc 4″. In Skåne (Southern Sweden) the „Gäravallen“, an upheaved marine littoral formation rests on peat; in Gotland, in the British Islands (Carse-clay etc.), indeed, even in North America, the same oscillation of the sea may be traced; it was without doubt too great, to be capable of explanation by local circumstances, compression of beds of peat by shifting sand-dunes etc.

We have seen, above, that the land (cfr. *Howorth* and *Suess)*, in many places in the higher latitudes, rose considerably in the Post-glacial age, and that a corresponding lowering took place in the warm coral-oceans. The last oscillations have therefore included large parts of the Globe. From this we must conclude that the same was the case with the oscillations also in the former ages, and that they are caused by general cosmic conditions. The slight oscillation (arc 4″) forms an interruption in the great Post-glacial upheaval in higher latitudes. A similar interruption in the lowering must, if our theory is correct, be found in the tropics; and, in fact, there are found, both in America's and the Old World's equatorial regions, numerous proofs of such a slight post-glacial oscillation in coral-reefs which are upheaved a few metres and now lie quite dry (vide *Suess* Antlitz der Erde, II, p. 630 ff.) These coral reefs probably date from the same period in which the peat beds of the north were inundated. The peat-beds, with the superimposed marine beds have again been upheaved, and the upheaved coral reefs have no doubt again begun to be lowered (at Bombay there is found a sunken forest-bed), but the process has not yet proceeded so far as to bring them below the surface of the sea.

We have still to make one or two remarks upon the Glacial age and its formations. The lignites of Dürnten in Switzerland are (cfr. *Heer)* contemporaneous with „the forest bed of Cromer." The fossils prove this. They contain nearly the same vegetable remains, the same extinct fauna. The lignites of Dürnten rest on, and are covered by, bottom-moraines, and are consequently „interglacial " They show 7 alternations of peat and forest beds, and may be fitted into the curve between the arcs 15′ and 1″. From this the Alps must, already in the Red Crag period, have had great glaciers. And in this there is nothing improbable, when we recollect that Leda arctica and other Arctic animals existed on the coasts of England, already at that period, and that the Chillesford beds indicate a far colder climate than the subsequent forest-bed of Cromer.

It is instructive to note, how each rise of the sea in England, during the Quaternary epoch, caused the inland ice to increase. This appears to agree with *Croll's* hypothesis that glacial periods are related to great eccentricities. But the distribution of glaciers in modern days shows that geographical conditions have the most important influence. Only when these are favourable can a high degree of eccentricity bring about the formation of an inland ice; if they are very favourable ice-periods may occur even with a slight eccentricity, as in Greenland in our own day. When the eccentricity rises the down-pour in the rainy periods also increases. If the sea is cold it will come down as snow. And in that manner, under favourable geographical conditions, the glaciers would increase as the eccentricity increased.

Also in North Germany there have been (cfr. *Jentzsch)* three ice-ages, with corresponding bottom-moraines (and oscillations?) and in the Alps there have been (cfr. *Penck* Vergletsch d. deutsch. Alpen) at least three ice-ages.

We have thus filled out the curve up till our own day, and connected the profile of the Basin of Paris with the present time. We will now trace the oscillations backwards, as far as the close of the Cretaceous period, in order to see, if possible, how many oscillations the geological period which is called the Tertiary contained.

The. Cretaceous period is divided from the Tertiary by a period of denudation, in which the land lay high in relation to the sea. The oldest marine formation in Europe, from the Tertiary period, is considered to be that at Mons in Belgium. It indicates the first oscillation, but that deluge does not appear to have left any traces in the other Tertiary basins. The first Tertiary deluge of the sea in the Paris basin formed the conglomerate at Rilly and Nemours. It was followed by an upheaval of the land, and the marine conglomerate became covered by the Rilly fresh-water lime-stone. To this oscillation in the Paris basin corresponds, probably, in Belgium, the so-called „systéme Heersien", at the bottom a purely marine formation, at the top containing, remains of land-plants. Then a new oscillation occurred and now England became partly covered by the sea. Here was deposited the marine Thanet sand, and over it the Woolwich and Reading series (Plastic clay), which is partly a brackish and fresh-water stage, and which shows that the beach-line had again retreated. In Belgium was formed, during that oscillation, the „systeme Landenien", at the bottom a purely marine formation and at the top brackish. In the Paris basin the marine sand at Bracheux was formed, and was followed by a fresh-water formation containing brown-coal (Lignites de Soissonais). Now followed a new rising of the sea level and after that again an upheaval. This has left no trace in the Basin of Paris, but, in England, the London clay was formed, and in Belgium the „systeme Yprésien." London clay begins with a littoral formation of shingle or gravel (Oldhaven beds), and the upper part of the stage shows that the sea again became shallower in consequence of a new upheaval of the land. This stage, as was shown above, contains at least 11 alternations, and therefore probably corresponds with at least two arcs of the curve. The „systeme Yprésien“, in Belgium, is divided into two sub-stages; the oldest, clay containing foraminifera; the youngest, sandy, containing numerous fossils, and therefore, doubtless, indicating a shallower sea. A new deluge formed, in Belgium, the marine „systeme Panisélien“ (sand), and, in the Paris basin, the marine sand of Cuise. With this the lower Eocene epoch is closed. It has, thus, in all probability, 6 oscillations.

The middle Eocene is represented in France, principally, by coarse lime-stone (Calcaire grossier). In that „stage“ there are 5—6 „sub“-stages, and in several places breaks in the series of beds. The middle Eocene is, upon the whole, marine, but with intercalated fresh-waters layers; and it also probably represents 6 oscillations. In Siebenburg it begins (cfr. *Koch* in Földtani Közlöny 1883, p. 118 ff.) with alternations of clay and marl, superimposed on which are alternations of gypsum and marl (lower gypsum horizon, 1st oscillation). Above that, marine layers: The perforata beds, from below and upwards α) an oyster bed, β argillaceous marl, γ) calcareous marl (lower striata-horizon), δ) a shell bed (lower perforata horizon), ε) Clay (upper striata horizon, the second oscillation?), ζ) Clay with a few hard marl beds, and containing the same kind of fossils as β, η) another oyster-bed, ϑ) Clay with oysters, ι) calcareous marl, upper perforata horizon (the third oscillation?). Above that the Ostrea clay, a thick clay with oysters and marl beds, and a sandy calcareous bed in the middle (fourth oscillation). Above that the lower coarse lime-stone, usually in two thick beds (fifth oscillation), covered by a thick bed of clay containing intercalated layers of sand, and probably a fresh-water formation, and at the top, covered by fresh-water lime-stone. Finally, the last (6th) oscillation: the upper gypsum horizon; gypsum alternating with clay, and above that coarse lime-stone alternating with gypsum; in other places foraminiferous clay, marine, the upper coarse lime-stone. I have stated all those details in order to show that those layers, all of which are contemporaneous with the Calcaire Grossier of the Paris basin, appear to indicate 6 oscillations.

Above the Calcaire Grossier begins the upper Eocene, with the continuous series of beds of the Paris basin described above.

The lower and middle Eocene appear, thus, to contain 12 oscillations, of which 6 relate to each of the two subdivisions of the epoch. With this the first cycle of the curve is filled out, in such manner that the beginning of the cycle will about coincide with the margin of the Chalk and Eocene. The middle Eocene has 25 alternations of strata in the Paris basin and probably some breaks. 6 oscillations correspond to about 25—30 periods of precession.

At the commencement of the cycles the mean value of the eccentricity is low, it increases in the middle of the cycle, and again sinks towards the close. The position of the beach-lines must also depend on the mean value of the eccentricity. But as it increases very slowly, through very long periods, it will be a very long time before its influence is visible on the solid Earth. The middle of the cycles ought, thus, to correspond to the transgressions of the sea, and the close, to the periods of denudation that divide the formations. Breaks in the series of beds may thus be expected in the higher latitudes, specially at the limit between the cycles.

The margin between Chalk and Eocene is indicated by what *Suess* (vide Antl. d. Erde II, 7ter Abschnitt, p. 376 ff.) calls a negative phase; the sea had retreated in the higher latitudes. During the Eocene epoch it again rose, and the Eocene seas had a wide distribution: we find their formations even in the centre of Upper Asia. The margin between Eocene and Oligocene is again distinguished by a negative phase. In the latter part of the Oligocene epoch, and still more in the Miocene, the sea again rose; between the Miocene and the Pliocene it retreated far backwards, and in the beginning of the Quaternary epoch it again rose. And similar great oscillations are traceable also in North America and in Patagonia. The Miocene marine beds are, however, absent in the last-named place, where the Miocene fresh-water beds are accompanied by great masses of volcanic products.

In the beginning of the Tertiary epoch, when the sea, in the higher latitudes, had retreated far back, the climate of Europe was (cfr. *Saporta:* Le monde des plantes avant l'apparition de l'homme. Paris 1879) temperate rather than tropical. According as the sea rose and the Eocene transgression proceeded, the climate became warmer, and at the close of the Eocene epoch the climate of South Europe was hot and dry. The rich Tertiary flora of the Arctic regions is (cfr. *Saporta* and *Gardner*) rather Eocene than (as *Heer* thought) Miocene. At the margin between the Eocene and the Oligocene the sea retreated, and the Arctic Tertiary flora began to migrate into Europe, supplanting the southern plants. Then came the Miocene transgression, and with it a rich tropical or subtropical flora. But just as the Miocene sea retreated, the flora of Europe lost, little by little, its richness and beauty, and the tropical elements became more rare. During the Pliocene epoch the sea retreated still farther, and the climate became colder and colder until the Glacial age arrived. But the last Quaternary transgression has, again, after several oscillations, compelled the ice to retreat, and our climate has again become temperate. There is thus a distinct connection between the climate and the geographical conditions. Great seas in higher latitudes bring warm climate and *vice versa.*

Now, we have seen that these great geographical changes were, in all probability, a consequence of the mean value of the eccentricity rising and sinking, and we must therefore believe that those great changes in the climate had a cosmic origin, and appeared at the same time over the whole Globe. As yet we know too little of the geology of the tropical regions, but there is reason to believe that there, also, great changes have taken place in the division of land and sea, and that these changes must, also, have had influence on the climate of the warm countries.

It is, still further, probable that the force of volcanicity stands in relation to changes of the eccentricity. Each of the great geological formations, quite from the pre-Cambrian epoch, has (cfr. *A. Geikie's* Textbook p. 259—260) had its volcanoes, and we have seen, above, that the same author states that there have been epochs in the Earth's history when volcanicity was far stronger, and wider distributed than at other epochs. We have seen how the upheavals of the land were accompanied by volcanic eruptions, and as regards the Tertiary period, at any rate, it appears as if the great transgressions of the sea were followed by periods in which the solid land began to rise during violent and widely distributed volcanic eruptions.

In order to aid in the survey, we will, finally, name all the arcs of the curve and the geological stages supposed to correspond to them. We will, to some extent, adopt the designations that *Charles Mayer-Eymar*[1] has given them.

Lower Tertiary, Eocene. Cycle I of the curve.

Lower Eocene, arcs 1—6.

Extending from 3,250,000 till 2,720,000 years before the present time.

Arc 1. The Montian Stage?
„ 2. The Heersian Stage.
„ 3. The Suessonian Stage.
„ 4. The Lower Yprésian Stage? } Londinian.
„ 5. The Upper Yprésian Stage? }
„ 6. The Paniselian Stage.

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[1] Vide his valuable „Classification des terrains tertiaires.“ Zurich 1884. He divides his stages into two sub-stages, one with „mers amples“ and one with „mers basses.“ Several of his stages, however, represent several oscillations. He thinks that the precession of the equinoxes is the cause of the changes in the level of the sea. According to his view the entire Tertiary and Quaternary periods must have had a duration of only a little more than 300,000 years. He leans for support on *Schmick's* untenable hypothesis of the sea-level being dependent on the precession.

Middle Eocene

Extending from 2,720,000 till 2,150,000 years before the present time.

7—12 The Parisian „Stage“ with 6 oscillations.

Upper Eocene

Extending from 2,150,000 years till 1,810,000 years before the present time.

13—16 The Bartonian „Stage“, with 4 oscillations.

Upper Tertiary, Cycle II.

Oligocene

Extending from 1,810,000 years till 1,160,000 years before the present time.

1′—4′ The Ligurian „Stage“, with 4 oscillations.
5′—7′ The Tongrian „Stage“, with 3 oscillations.

Miocene

Extending from 1,160,000 years till 700,000 years before the present time.

8′ The Aquitanian Stage?
9′ The Langhian Stage.
10′ The Helvetian Stage.
11′ The Tortonian Stage.
12′ The Messinian Stage.

Pliocene

Extending from 700,000 years till 350,000 years before the present time.

13′ The Matérin Stage.
14′ The Plaisancian Stage.
15′ The Astian Stage.
16′ The Arnusian Stage.

Quaternary, Cycle III.

Extending from 350,000 years before the present time till now.

1″—3″ The Saharian „Stage“ with 3 oscillations.

The limits between the cycles of the curve are not drawn at random. The beginning and close of the first two cycles distinguish themselves by their unusually low degree of eccentricity. The last arc of the cycle and the first arc of the succeeding one have, together, a duration of about 150,000 years, and through all that time the eccentricity is very low. In these two cycles the greatest mean eccentricity occurs also in the middle of the cycle.

The Eocene epoch appears to have had 16 oscillations, and should correspond with the first cycle; the Oligocene, Miocene, and Pliocene have, also, together, 16 oscillations, and correspond to the second cycle. The lower Eocene corresponds to the arcs 1—6; the middle Eocene to 7—12; and the upper Eocene to 13—16. In the same manner, the Oligocene corresponds to the arcs 1′—7′; the Miocene to 8′—12′; and the Pliocene to 13′—16′.

There is, thus, a certain analogy between the lower and the upper Tertiary epochs. We have 6 divisions which nearly correspond to each other in the following manner:

The lower Eocene to the Oligocene; the first-named with 6, the last-named with 7 oscillations.

The middle Eocene to the Miocene; the first-named with 6, the last-named with 5 oscillations.

The upper Eocene to the Pliocene; both with 4 oscillations.

The great transgressions of the sea occur in the middle of the cycles, in the middle Eocene, in the upper Oligocene and the Miocene. The mean value of the eccentricity was greatest in the middle of the cycles. At the commencement and in the last part of the cycles, when the mean value of the eccentricity was small, the sea retreated far back: e. g. between the Chalk and the Eocene, in the upper Eocene and the Pliocene.

The thought therefore presents itself, with great reasonableness, that there is a connection between the cycles in the curve representing the eccentricity of the Earth's orbit and what is called a geological epoch, or as it has also been called a „cycle“ or „circle of deposition.“ The two Tertiary cycles resemble great stages that are each composed of 16 small ones. Just as each of these 16 small stages represents a slight oscillation of the sea, so does each cycle represent a great oscillation; but that great oscillation has been contained in, and completed itself through, the 16 smaller ones. In the same way the mean value of the eccentricity rises and falls in each cycle with 16 oscillations. It is low at the beginning of the cycle, it attains it greatest value in the middle of the cycle, and sinks again towards the close of the cycle. The agreements between the cycles of the curve and the epochs, between the arcs of the curve and the stages, and between the number of the arc's precessions and the alternations of the strata in the stages, wherever they could be controlled, appear, to me, to be so striking that they exclude the thought of an accidental coincidence, and distinctly point to a cause and effect relationship.

If we would attempt to test the correctness of the hypotheses I have presented, with the aid of the older formations, then we must bear in mind the following. *Geelmuyden* has, after investigating the laws regulating the changes in the eccentricity, stated to me that it is likely that a cycle of about 1,500,000 years must appear in the curve; but we cannot without more extended investigation conclude that it will continue unchanged during unlimited periods. Even in the calculated curve the cycle III distinguishes itself from the two others by a much lower eccentricity in the arcs 4″ to 9″.

If the Earth's oblateness in ancient times was greater, then the period of precession was also shorter. It would (cfr. *Geelmuyden)* be very nearly proportional to the square of the time of rotation. To a rotation of 16 hours corresponds e. g. a (synodic) precessional period of 10,000 years, consequently only the half of the present. The shorter the period, the less distinguished (all other things being alike) must the climatic period be, and the more indistinct the alternation of the strata.

Then we must recollect that in Palæozoic and Mesozoic eras the Moon was probably much nearer. The lunar-tide was, in that case, in itself, much stronger and more powerful in relation to the solar-tide than now. The sidereal day was shorter and the stronger tidal wave acted more frequently. The shores became more speedily destroyed. The formation of beds, doubtless, took place more rapidly. The sidereal day increased more rapidly in length than now. All these relations must have had influence both on the form of the Earth, the division of land and sea, the displacement of the beach-lines, the changes of climate, the ocean currents, the distribution of chemical and mechanical sediments, and the alternation of strata, so that we cannot, without taking all these and possibly yet other relations into consideration, prove the applicability of the hypotheses to the series of beds pertaining to the Palæozoic and Mesozoic eras.

Finally, I will, in a few words, refer to the chief points in my hypothesis.

The precession of the equinoxes and the periodical change in the eccentricity of the terrestrial orbit are reflected on the geological series of strata, and are the key to the calculation of the duration of epochs.

The precession causes the winter and summer to be alternately longer and shorter. In the semi-period when winter is longer than summer, the distinction between inland- and coast-climate becomes more prominent. The currents of the atmosphere become stronger. In consequence of that the ocean currents increase in strength, and that again reacts on the climate. The periodical change of the climate produced by the precession is not great, but is sufficient to imprint itself in the alternation of beds, and in the formation of beach-lines, terraces, series of moraines etc. To each period of precession corresponds one alternation of strata.

The eccentricity of the Earth's orbit is periodically changeable. It's mean value rises and falls for a period of about $1^1/_2$ millions of years, with 16 oscillations. Such a rise and fall I term a cycle, and each cycle is, in the calculated curve. composed of 16 arcs.

The tidal-wave, which is the most powerful agent in altering the sidereal day and in lengthening it, rises and falls, in some measure, with the eccentricity. It so exceeds the other forces that act in altering the length of the day, that the day steadily becomes lengthened, on the average, more quickly in the middle of the cycles, when the mean value of the eccentricity is greatest, and more slowly at the limit between them, when the eccentricity is least; and in respect of the respective arcs with increasing speed during rising, and decreasing speed during falling eccentricity.

The interior of the Globe is plastic owing to the great pressure. The surface or „crust“ opposes the greatest resistance to change of form. But according as the sidereal day becomes lengthened, and the equatorial regions of the Earth increase in weight, a steadily increasing strain acts outwards towards higher latitudes, and that strain increases until the resistance is overcome. We must also bear in mind that forces which are too slight to produce a sudden change in a solid body may still produce a change of form when they act through long periods.

Therefore the lengthening of the sidereal day acts not only on the seas, but also on the form of the solid Globe. The Earth approaches, steadily, more and more to the spheriform, but the solid crust is more sluggish in its movement than the seas, which immediately accommodate themselves to the altered time of rotation.

As the motive force of these movements of seas and solid Earth is periodically changeable, according to the eccentricity of the Earth's orbit; these movements take place also, periodically, quicker and slower. And as the seas always accommodate themselves to the forces before the dry land does, it is likely that the beach-lines come to oscillate up and down once, for each rise and fall of the eccentricity of the Earth's orbit. That is the case in respect of both, the respective arcs of the curve and of the cycles. In such a cycle „the mean level of the sea" rises and falls once in 16 oscillations.

The sidereal day has (cfr. *Darwin*) become several hours longer. It is therefore probable that there must have accumulated such a great strain in the mass of the Earth, that a slight increase of the strain would be sufficient to cause changes of form at the weakest points. It is also likely that those partial changes in the solid mass of the Earth must occur, especially, at times of great eccentricity, or some time after such an occurrence, when the motive force increases quickest.

The change in the tidal-wave caused by the variation of the eccentricity, is presumed to be sufficiently great to explain the displacement of the beach-lines. A few metres of vertical displacement of the beach-line is sufficient to produce, in the deeper basins, an alternation of many metres of thick marine and freshwater beds. And as regards the changes in the solid body of the Earth, we must recollect that the series of beds is not complete at any single spot. In other words, the oscillations were not general to such an extent that they were contemporaneous everywhere. Only by partial changes of form, sometimes here, sometimes there, always at the weakest points in each age, has the solid Earth approached to the spheriform. To each arc of the curve there corresponds, therefore, only a partial and not a general change in the form of the solid Earth. And the oscillation of the beach-line, corresponding to the arc can, therefore, not be pointed out everywhere, but only in the basins where the forces at that time exerted their effect. In this way we can obtain a perfect profile only by combining layers of all the Tertiary basins. Neither were the changes of the solid Earth everywhere equal in extent, but were greatest at the weakest points of its surface, so that quite extensive local upheavals may be caused by slight changes in the length of the sidereal day.

That is the case as regards the individual oscillations, but even the great transgressions of the sea, of which one occurs in each cycle, need not be owing to any very great rise of the sea-level; as great flat-lands may be covered and drained by a relatively small vertical displacement of the beach-line. But those great changes in the distribution of land and sea were, sure enough, sufficiently great to produce considerable changes of climate. Extensive seas in higher latitudes cause their climate to be mild and *vice versa.*

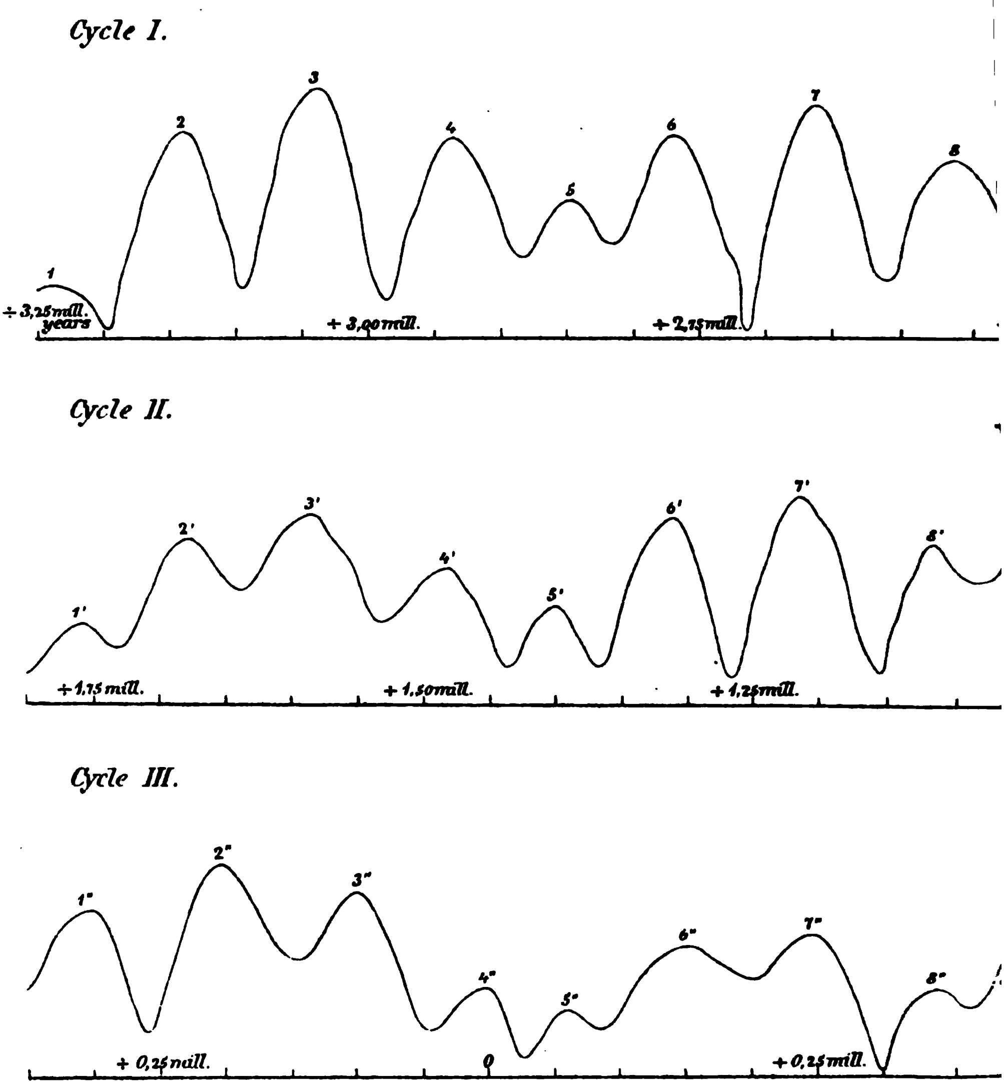
If we now compare, keeping these principles in view, the curve of the eccentricity with the geological series of beds, we find an agreement indicating that the hypotheses are correct. The two cycles of the calculated curve correspond to two geological cycles. Each of the cycles has 16 arcs that correspond to 16 slight oscillations of the beach-lines or 16 geological stages. In each of these stages there are as many alternations of strata as there are precessions in the corresponding arc. And the mean sea-level rises with the mean eccentricity in the middle of the cycles, and falls at the limit between them, and, hand in hand with the mean sea-level, rises and falls, also, the temperature in the higher latitudes.

The doctrine here discussed agrees with *Lyell's* great principle. Slow changes in the length of the winter and summer and in the force of the tidal-wave, produce periodical changes of climate, and displacements of the beach-lines. The Earth changes its form slowly and imperceptibly. The changes take place so slowly that the effects, first, after expiry of many thousands of years, begin to appear distinctly. There are two astronomical periods which are the causes of the great and radical changes, of which geology bears to us testimonies from far remote ages, and which will still continue in the future, for millions of years, to produce similar changes in the geography of the Globe, its climate, and its animal and vegetable life.

Trykt 13 december 1888.

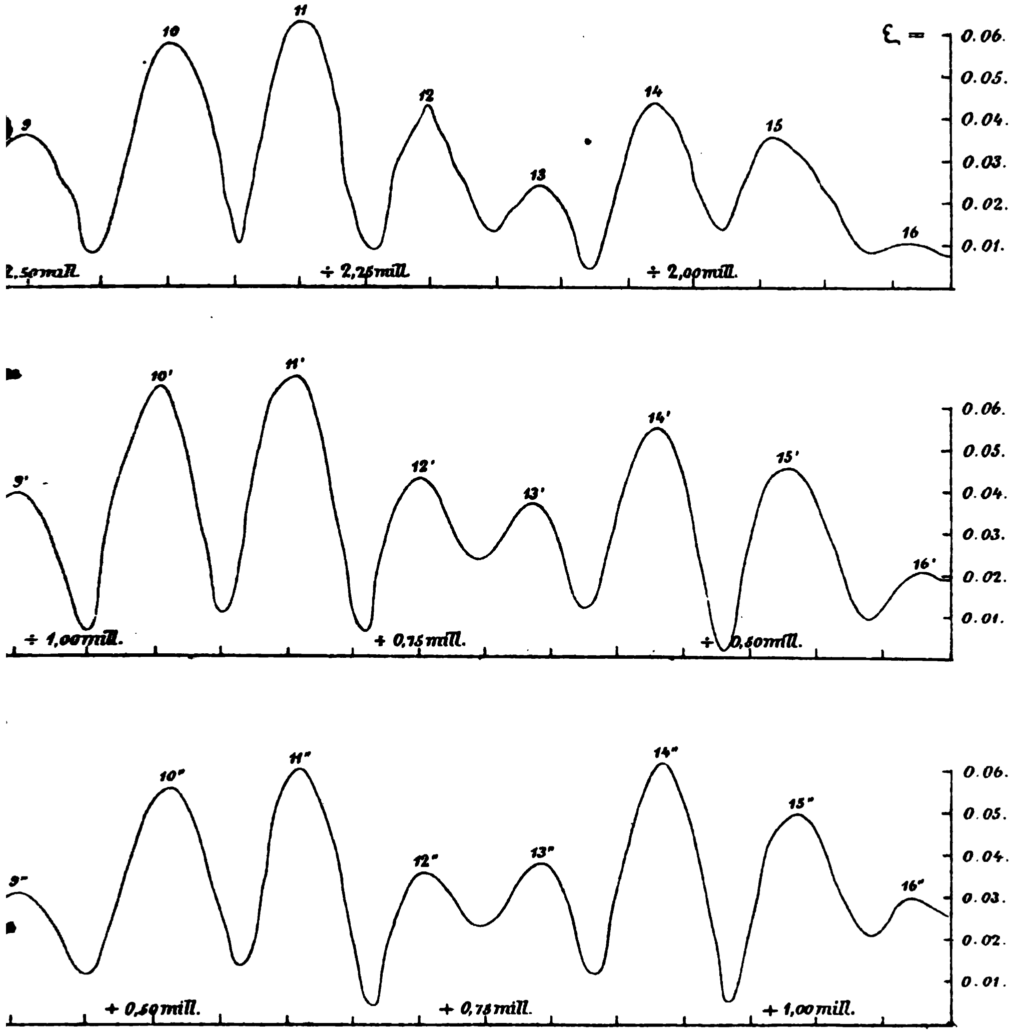
Eccentricity of

calculated according to Stockwell's formula by R.W.Mc.



earth's orbit,

nd (Amer. Journ. of Science, ser. 3 vol. 20. New Haven 1880).



ADDITIONAL NOTE

TO

THE PROBABLE CAUSE OF THE DISPLACEMENT OF BEACH-LINES

BY

A. BLYTT.

Additional note.

A mistake has been made above in placing the Headon beds of the Isle of Wight in the Upper Eocene. The causes which led to this mistake were: a certain stratigraphical similarity between the Calcaire de St. Ouen and the Osborne, both being fresh-water formations with the same number of alternations; then the difficulty in deciding the true number of climatic alternations in the fluvio-marine beds of Wight. Though I was, indeed, well aware of the fact, that the fauna of the Middle Headon is Oligocene, I thought it not quite impossible that the Oligocene fauna might have immigrated earlier into the Hampshire basin than elsewhere in Europe. But the difference between the faunas of the Grès de Beauchamp and the Middle Headon is far too great. These two faunas cannot prosibly be synchronous. And it is the more superfluous to make the above named supposition, because, as will be presently shown, the Isle of Wight profile may be fitted into the curve of eccentricity in a manner, that agrees exactly with palæontological evidence.

In the Paris Basin where sedimentation went on very slowly and where chemically deposited layers are much more prominent, it is less difficult to determine the number of climatic alternations. But it is otherwise in the Isle of Wight. In these beds many irregularities occur; there are many lenticular intercalations, and as the vertical cliffs break down, the minor details of the profiles are often altered. This is a natural result of the mode in which these beds were formed. They are fluviatile and estuarine. The river has eroded and shifted, banks and shoals have been formed, and such occurrences have produced many irregularities in the strata.

After a renewed examination of the descriptions given by *Forbes*, in his masterly work on the Oligocene beds of Wight, I have, however, found that in these beds, too, the number of climatic alternations may be pretty well fixed; I have found that this number is not quite so great as I formerly supposed, and that the whole series corresponds in a beautiful manner with the curve of the eccentricity of the earth's orbit and in a manner that agrees completely with the palæontological evidence.

Besides the more inconstant beds we find in this series others which are very regular and constant. In my researches on the peat mosses,[1] I have shown, that the layers of tree stumps, occurring at intervals in the peat, often divide between peat layers with a different fossil flora. These forest beds, therefore, show that the formation of peat was arrested several times by dry periods of very long duration, since we see that the flora, during these interruptions in the peat building, was more or less changed.' In the marine beds the dry periods are predominantly represented by chemically formed layers such as banks of limestone, beds of ironstone, layers of septaria etc., whilst, in the rainy periods, the rivers swelled and more or less thick beds of mechanical sediments, as clay, mud, and the like, were deposited. And, as in the peat mosses the forest beds often show a long interruption in the peat forming, so, likewise, do many of these marine and fluviatile chemical beds point to a long interruption in the deposition of mechanical sediments. We often find that limestone banks and layers of septaria divide between mechanical deposits with more or less different faunas and form, thus, a division between stages and substages of the geological series. In the fluvio-marine beds, which form the subject of the present note, we find several such instances as we shall presently see.

I will now go on to describe, according to *Forbes*, the main features of the Oligocene beds in the Isle of Wight.

The Upper Eocene Barton clay has 5 layers of septaria. It is synchronous with the Grès de Beauchamp of the Paris basin and it must consequently, like this, correspond to the arc 14 of the curve. This arc represents 100000 years and, consequently, about 5 periods of precession. The Barton clay is covered by the Headon sands, which show no alternations and may have been formed in a comparatively short time.

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[1] Cfr. A. Blytt: Essay on the Immigration of the Norwegian Flora during alternating rainy and dry periods. Chria. 1876 p. 54—56.

Between the Eocene and the Oligocene a great break exists in the Isle of Wight. To this break, in the Paris basin, corresponds the fresh-water Calcaire de St. Ouen. This is only 6—7 metres thick and shows 10 alternations of strata. Consequently, according to my hypothesis, the Calcaire de St. Ouen ought to represent about 200000 years. This would seem to be a rather long time for the forming of only 6—7 metres of limestone. But it should be kept in mind, that, during the deposition of these 6—7 metres of fresh-water limestone, the marine fauna was radically changed. The Calcaire de St. Ouen divides between two geological formations, the Lower and the Upper Tertiary. Of the Middle Headon marine animals, according to the Quart. Journ. Geol. Soc, vol. 37, p. 111, only one half to one third belongs to Barton forms. And the Calcaire de St. Ouen, probably, represents more than half of the interval that lies between the marine beds of Barton and Middle Headon. During the deposition of the Calcaire de St. Ouen no beds were formed in the Hampshire basin which probably was then not submerged in the sea.

But the sea rose again and the Oligocene period commenced. The first Oligocene stage, in the Isle of Wight, is the Lower Headon, a fresh-water and brackish formation, showing one oscillation of the beach-line. Marine shells (Cytherea, Mytilus) sometimes occur in the middle beds of the stage, whilst the lower and upper ones contain a fresh-water and brackish fauna. I have, above, for this stage reckoned 7—8 alternations of strata. The stage contains 5 limestone banks separated by clays and sands and has, moreover, two horizons with iron concretions. It thus shows 7 alternations.

The next stage or oscillation of the beach-line is represented by the Middle and Upper Headon. These have, together, 6 alternations, 4 limestones and 2 layers with iron concretions, separated by clays and sands. The Middle Headon is brackish at the base but soon shows a marine fauna,[1] the Upper Headon is a brackish and fresh-water formation.

Above the Headon we have the Osborne beds, the most unmixed fresh-water formation of the whole series. It is very variable, but shows, in some places, 8—10 alternations: 2 septarian layers, 2 bands of ironstone and 6 horizons of concretionary limestone with intervening clays and marls. 10 alternations represent two oscillations and two arcs of the curve.

The Bembridge stage covers the Osborne. First there is a fresh-water building, the Bembridge limestone, which very constantly shows three alternations of compact limestones with clay and marl. The Bembridge limestone is covered by the marine Bembridge Oyster-bed and close above this again there comes a layer of septarian stone, according to *Forbes* „very remarkable and constant." The Lower Bembridge marls succeed with brackish and fresh-water fossils but without alternations and are covered by another layer of septaria „sometimes siliceous, sometimes calcareous," and this divides between the Lower and Upper Bembridge marls. In these Upper marls, which, like the Lower ones, contain brackish and fresh-water fossils, indeed even lignites, I formerly thought there was evidence of 4 climatic alternations: there are 2 minor bands with pyrites, one more marly bed, and at the top of the series a layer of iron concretions covered with marl. But I now think it likely that the marl and the 2 pyrite layers do not mark climatic changes. If we only reckon with the „remarkable and constant" septarian layers, then the Bembridge marls show only 3 alternations of climate, and we should, thus, for the whole stage have 6 climatic periods. The Bembridge stage, consequently, tells of one oscillation of the beach-line with 6 climatic alternations.

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[1] In the sections of the Middle and Upper Headon, given by *Keeping* and *Tawney* (Quart. Journ. Geol. Soc. vol. 37, pp. 91, 103), there are more marine and less fresh-water alternations than in the sections of *Forbes*. But the total number of alternations appears to be the same.

Finally, we come to the Hamstead (Hempstead) stage. The lower part of that stage is formed by fresh-water and brackish marls showing, besides 1—2 pyritiferous beds of minor importance, two remarkable climatic periods. One dry period is marked by the „White Band", a more or less indurated ferruginеous layer rich in fossils, another by a layer of ironstone concretions. The „White Band" divides between the substages Lower and Middle Hamstead marls, the ironstone band occurs very near to the limit between the Middle and Upper marls. The whole is covered by the marine Corbula beds with one layer of septaria. The Hamstead stage thus represents one oscillation with three climatic alternations; but it is not complete, the top being destroyed by denudation.

The fluvio-marine Oligocene series in the Isle of Wight shows, thus, the following oscillations with the following number of climatic alternations:

Lower Headon, one oscillation, 7 alternations.

Middle and Upper Headon, one oscillation with 6 alternations.

Osborne, 8—10 alternations and probably 2 oscillations.

Bembridge, one oscillation with 6 alternations.

Hamstead, one imcomplete oscillation with 3 alternations.

In this series we have three purely marine horizons: the Middle Headon, the Bembridge Oyster bed, and the Hamstead Corbula beds. If we now arrange our series from Wight according to the curve of eccentricity, we see how admirably well they correspond. The Lower Headon corresponds with the arc 2′ with 5 periods of precession and, as it shows 7 alternations, probably also to the last part of arc 1′. The Middle and Upper Headon, with 6 alternations, correspond with the arc 3′; the Osborne, with 8—10 alternations, to the arcs 4′ and 5′; the Bembridge, with 6 alternations, corresponds with the arc 6′ and, finally, the incomplete Hamstead, with only 3 alternations, with the first half of the arc 7′. The 3 marine beds of the series thus correspond to the three highest eccentricities

(3′, 6′, 7′), the Osborne, which has the most unmixed fresh-water fauna, corresponds with the two lowest arcs (4′, 5′).

For comparison's sake we will again study in detail the profile from Méry-sur-Oise in the Paris basin and compare it with Stockwell's curve in ascending order. The beds we will number in the same manner as in the original description, given by *Dollfus* and *Vasseur* in Bull. Soc. Géol. de France ser. III, vol. VI. Paris. 1878. p. 243 ff.

Sables de Beauchamp et Mortefontaine etc. (beds 89—111). Arcs 14 and the first half of 15. In these marine (and partly brackish?) beds we have at the bottom a pebble bed, above which come at first 5 sandstones alternating with sand, then a limestone and a calcareous marl with intercalated sand and marl, showing thus 6—7 alternations.

Above these sands lies the Calcaire de St. Ouen (beds 112—142), a fresh-water formation, divided by a marine layer (bed 128) into two subdivisions. The lower, from the top of arc 15 to the top of arc 16, has 4 horizons of hard or siliceous limestones alternating with marls. Then comes the marine bed (128) at the top of 16. (This arc, in the curve of *Leverrier*, ascends higher than in *Stockwell's* curve). In the upper subdivision we have again hard and siliceous limestones alternating with marls and clays 6 times. It thus finishes somewhat to the left of the top of arc 2′.

Sables de Monceaux (beds 143—145) is a marine sand with 3 layers of concretions. Arc 2′.

Marne à Pholadomya (beds 146—154) two marine alternations of siliceous limestone with marl.

Gypse n. 3 (beds 155—158). One alternation of marine marl and gypsum.

Marne à Lucina bed 159. No alternation.

The beds 146—159 have, thus, together 3 alternations and correspond to the arc 3′.

Gypse n. 2 (beds 160—196) marine, at least for a great deal. It should, however be observed, that no fossils are indicated for the last part of the stage, which may perhaps be brackish. In this stage gypsum alternates with marls about 5 times. The main gypsiferous horizons are the beds 161, 171—176, 178—186, 191 and 194. The stage corresponds to arc 4′.

Gypse n. 1 (bed 197). A massive gypsum 8 m. thick, with fresh-water fossils, representing 1 alternation. Between arcs 4′ and 5′.

Marne bleue (beds 198—204) and Marne blanche (beds 205—209) are fresh-water marls alternating with marly limestones and ferrugineous marls 4—5 times. Arc 5′ and the first third of arc 6′.

Marne verte (beds 210—217) a brackish formation with 2 alternations of clay with marl and siliceous limestone. The top of arc 6′.

Calcaire de Brie (beds 218—220), a fresh-water limestone; perhaps we have here indications of more than one climatic alternation, because the limestone alternates with marl 3—4 times, though in rather thin bands. The place of these beds is between the arcs 6′ and 7′.

Marne et mollasse marine (beds 221—231). Clay alternating with marly limestone and sandstone 2—3 times. The highest part of arc 7′.

Sables de Fontenaye (bed 232) marine sand interstratified with clay but, as it appears, without more remarkable alternations. Latter part of arc 7′.

Calcaire de Beauce inférieur, fresh-water, between arcs 7′ and 8′.

We thus get the following table showing the contemporaneous beds of both basins:

Paris:	*Wight:*
Grès de Beauchamp.	Barton clay.
Sable de Mortefontaine etc.	Sands of Headon Hill.
Calcaire de St. Ouen.	Wanting.
Sables de Monceaux.	Lower Headon.

Paris:	*Wight:*
Marne à Pholadomya.	Middle and Upper Headon.
Gypse n. 3.	
Marne à Lucina.	
Gypse n. 2 – 1.	Osborne.
Marne bleue.	
Marne blanche.	Bembridge limestone.
Marne verte.	Bembridge Oyster bed.
Calcaire de Brie.	Bembridge and Hamstead marls.
Marne et mollasse marine.	Hamstead Corbula beds.

And this arrangement completely agrees with the palæontological evidence. The Middle Headon is considered by palæontologists to be synchronous with the Gypse marin, the Corbula beds with the Lower Sables de Fontainebleau, and they correspond respectively with the same arcs. The intervening series of beds contains, in both basins (the Parisian and the Hampshire one) almost the same number of alternations. I cannot help thinking that this shows, that the alternation of strata was effected by a general cause, and it seems highly probable that this cause is the precession of the equinoxes. And as the curve of the eccentricity of the earth's orbit may be said to be, at the same time, a curve showing the oscillations of the sea level, these oscillations must, from some cause or another, be dependent on the variations of the eccentricity. I would now ask geologists to test the correctness of my views by comparing as many Tertiary profiles as possible with the curve.

Corrigenda.

p. 5, line 15 from top for „southern“ read „lower“.

p. 17, l. 13 from bottom after „currents“ add: „It should, however, be remarked, that the numerical values given above are by no means pretended by *Darwin* to be the real ones. He only works out the maximum speed at which these changes could possibly have occurred. So we cannot get any time scale out of his views.“

p. 22, l. 11 f. t. for „$\frac{1}{150}$“ read „$\frac{1}{525}$“.
18 f. t. for „$\frac{1}{150}$“ read „$\frac{1}{525}$“.

p. 23, l. 4 f. t. for „*Darwin* assumes many times as great changes as *Thomson* does,“ read „*Darwin* allows as possible much greater changes than those corresponding to the calculation of the present retardation as worked out by *Thomson* (vide infra p. 24).“

p. 29, l. 15 f. t. for „quarternary“ read „Quaternary“.

p. 47, l. 10 f. b. for „Upper Bagshot“ read „Sands of Headon Hill“.

p. 47—48. For the survey given of the Oligocene beds of Wight the following should be substituted:

„Lower Headon, fresh-water and brackish, 5—7 alternations, arcs 1′ (p. p.) and 2′.

Middle Headon, partly marine, and Upper Headon, fresh-water, and brackish, together with 5 alternations (arc 3′).

Osborne, fresh-water, 8—10 alternations (arcs 4′ and 5′).

Bembridge Limestone, fresh-water, 3 alternations.

Bembridge Oyster bed, marine.

Bembridge Marls, brackish and fresh-water, 3 alternations. (The Bembridge corresponds with arc 6′).

Hamstead Marls, fresh-water and brackish, 2 alternations.

Hamstead Corbula beds, marine, 1 alternation. (The Hamstead corresponds with part of arc 7′).“

p. 48, l 13 f. t. for „When we bear that in mind“ read „Nevertheless“.

p. 48, l. 14 f. t. for „corresponds, at any rate, tolerably well“ read: „corresponds exactly“.

p. 48, l. 18 f. t. for „nearly double“ read „more than triple“.
for „80“ read „48“.

p. 51, l. 9—10 f. b. for „Anversian and the Scaldisian“ read „Lower and Upper Scaldisian“.

p. 51, l. 9 f. b. After „oscillations.“ add: „There is, in Belgium, still one Pliocene oscillation, the Diestian, which is older than the Crag and corresponds, probably, to the Vienna Congerian stage.“

Trykt 24de januar 1889.

The probable cause of the displacement of beach-lines

Second additional note

By

A. Blytt.

Second additional note.

(Read 15 February 1889.)

In the present additional note I will try to show more fully, that the hypothesis is sufficient to account for the geographical and climatic changes, which have taken place in the Tertiary and Quaternary periods.

The chief difficulty is the influence of eccentricity on the sea-level. This will be first considered.

We see how the earth's crust is rent by faults and built of fragments. Dislocations are of common occurrence showing that the fragments have been displaced in different degree. As the inner strain is relieved by dislocations, we may conclude, that the strain must vary in different places, and that it must vary at the same place at different times. In places, where the strain is great, earthquakes will probably be of more common occurrence.

It is well known that earthquakes are more common and destructive in some parts of the earth than in others. Most earthquakes are caused by dislocations. But these dislocations only rarely are great enough to be immediately observed. In New Zealand, during an earthquake in 1855, a certain part of the Northern Island was upheaved 0.3—3 metres. The upheaved part was cut off by a fault from parts, which were unaffected by the movement. The fault extended for two days journey. In one place a white band of Nullipores was lifted 3 m. above the level of the sea. At the same time some parts of the coast of the Southern Island were depressed 1.5 m.[1] Similar sudden risings are reported from the coast of Chile (by *Fitzroy* and *Charles Darwin*). *Darwin* was however not himself an eyewitness to the rising, and *Suess* is of the opinion, that no upheaval took place at that occasion, but that the ocean retired, and that the disturbance of the sea was so great, that it lasted a rather long time before the waters resumed their state of equilibrium.[1] The sudden dislocation in New Zealand is however admitted by *Suess*.[2] Another similar case is reported from Western North America by *G. K. Gilbert*.[3] He says: „The fault-scarps[4] of the Wasatch follow the western base. Those of the Sierra Nevada follow the eastern base; and it happens that one of them has been formed since the settlement of the country. It occurred in 1872, and produced one of the most notable earthquakes ever recorded in the United States. The height of the scarp varies from five to twenty feet, and its length is forty miles. Various tracts of land were sunk a number of feet below their previous positions, and one tract, several thousand acres in extent, was not only lowered, but carried bodily about fifteen feet northward.“ And thus we should have at least two undoubted cases of a visible dislocation in the solid rocks during earthquakes.

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[1] *Reyer*: Theoretische Geologie. Stuttgart 1888. p. 803.

Loose alluvial masses are sometimes displaced by earthquakes. This occurred in the Mississippi delta during an earthquake in 1811, and in the Ran of Kachh in India 1819. And in Achaja, in 1858, littoral sediments, by an earthquake in the underlying massive rocks, were suddenly submerged by a gliding movement, so that in some places only the tops of the trees were visible above sea level.[5]

In such cases the earthquakes are accompanied by visible dislocations in the crust of the earth. And we must indeed believe that earthquakes are caused in general by dislocations. A dislocation of some decimetres will in many cases be observed only with difficulty. And if we suppose the dislocation to be only one millimetre or still less, it will be quite impossible to prove it. In some countries earthquakes occur almost every day. In Switzerland, for instance, there are in one year about 100 earthquakes, in some parts of Japan earthquakes occur every other day. In New Zealand an earthquake in 1848 lasted for 5 weeks, and in some days up to 1000 different shocks were numbered.[1] Even in our own country earthquakes are not of very rare occurrence, and some extend from the west coast right across the country to the eastern parts.

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[1] Cfr. *Suess*: Antlitz der Erde I. p. 187.

[2] Antl. der Erde II. p. 34.

[3] Amer. Journ. of Sci. Ser. III. Vol. 27 (1884) p. 51.

[4] The „fault-scarps“, according to *Gilbert*, are formed by the rising of the mountains, but he also admits subsidence of the adjacent lowland. He expresses (l. c. p. 49) an opinion quite similar to that of *Dutton* (vide supra p. 10) in saying: „In the Great Basin the movements are vertical. It is as though something beneath each mountain was slowly, steadily and irresistibly rising, carrying the mountain with it.“

[5] *Suess* l. c. I. p. 61. *Reyer* l. c. pp. 701, 800 ff. *Neumayr*: Erdgeschichte I. p. 288.

It is well known that Scandinavia was upheaved in Post-glacial times. That the land has really risen is shown beyond doubt by the fact that the upheaval was very different in degree in different parts.

The upheavals and depressions of the solid crust of the earth, to which geology bears so numerous testimonies, were no doubt caused by the summing up of the effects of innumerable slight dislocations (earthquakes), each of them in most cases causing only an imperceptible displacement. As the centrifugal force diminishes during the lengthening of the sidereal day by tidal friction, strain accumulates in the solid earth, until the limit of resistance is reached. In higher latitudes there is on the whole a tendency to rising and in lower to sinking. And thus, in the course of time the effects of earthquakes are summed up, partly to upheaval, partly to subsidence, and such displacements after long periods may become very considerable. If a country is by numerous earthquakes every year upheaved to the extent of only one or two millimetres, this will in 100000 years cause an upheaval of 100 to 200 metres, and the mean upheaval of Scandinavia in Post-glacial times was certainly not greater than that. This view of the manner, in which continents rise or subside, I have formed independently, but I now see, that it has been propounded a long time ago by *Charles Darwin*, who supports it by the alleged sudden upheaval of the coast in Chile; as also more recently by *G. K. Gilbert.*[1]

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[1] *Reyer* l. c. pp. 694, 626.

In countries, where the inner strain has been relieved by great displacements in recent or late geological times, earthquakes probably will be rare, and less destructive than in countries, where there is still a great strain in reserve. And the great rising of Scandinavia probably has relieved the strain to a such degree, that earthquakes are now with us neither very numerous nor destructive.

From the observations it seems to follow, that earthquakes occur more commonly at some times than at others. The celebrated *Kant* was of the opinion, that the moon exerted an influence on the interior of our globe and on the volcanic forces. *Perrey, Volger, Fuchs* and *Schmidt* have published earthquake-catalogues. And from the researches made by them it seems to appear, that earthquakes are more numerous in the months from october to march than in the months from april to september. As now, when the northern hemisphere has its winter, the earth is in perihelion, it is believed, that the greater nearness of the sun produces more earthquakes. *Neumayr*[2] does not think this opinion to be correct, but *Reyer*[3] thinks it to be right. Both however agree, that earthquakes are probably more common during spring-tides. And *Neumayr* says, that the opinion, that earthquakes are more numerous under low barometric pressure, appears to him to be relatively well established.

It is clear, that such slight changes of pressure as those caused by the rise or fall of the barometer, and such small alterations of the forces as those effected by the varying distance of the sun and the moon, should not be able to cause disturbances in the solid earth, were it not for the fact, that great strains are accumulated by other forces, and that the earth is in many places strained to the very limit of elasticity. In such very weak places an inconsiderable force may be sufficient to release the strain, and we may in this manner understand, that even a change of barometric pressure should be perhaps sufficient to give rise to earthquakes.

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[1] Cfr. *C. Darwin*: On the Connexion of certain Volcanic Phenomena in South America; and on the Formation of Mountain Chains and Volcanos, as the Effect of the same Power by which Continents are elevated (in Transact. of the Geol. Soc. London. Series II Vol. V. London 1840 p. 607). *G. K. Gilbert*: A Theory of the Earthquakes of the Great Basin, with a practical Application (in Amer. Journ. of Sci. Ser. III. Vol. 27. 1884).

[2] Erdgeschichte I. p. 298 ff.

[3] *Reyer* l. c. p. 694 ff.

We will now investigate, whether the displacements of the beach-lines, which took place in the Tertiary and Quaternary times, were so considerable, that they cannot be explained by the aid of our hypothesis.

It is only in the folded chains, that Tertiary marine formations have been lifted to very considerable heights above the sea. But the folding is a local phenomenon. The folded chains of cainozoic age are few, and compared with the total surface of the globe they are of very small extent. If two great divisions of the crust, which are separated by a line of weakness, move in different directions at the same time or in the same direction at different times, great quantities of eruptive matter may be squeezed out at the line of weakness, and great local foldings may be caused at the same line by the different movements on either side; nay, even under lower latitudes, where according to the hypothesis all is sinking, great mountain chains may be elevated at such lines of weakness. In considering the highest and youngest mountain chains of our earth, we see that their site agrees pretty well with the hypothesis. The ranges bordering the Pacific run along the division between great continents and a deep ocean. It is, as shown above, probable that the effect of the decreasing centrifugal force is diminished by the movements of the sea, which immediately accommodates itself to the change in the length of the day, and that from this cause seabottom and land will not move contemporaneously. And the great chains, which run acrosss Eurasia, from the Himalayas to the Pyrenees and the Atlas mountains, were upheaved at the border of the great Tertiary Mediterranean sea, and they lie under latitudes where about we would expect the limit between the rising and sinking parts of the crust to be situated.

A similar line of weakness, which possibly divides between parts of the crust moving at different times, is the volcanic line from Scotland across the Faroe Islands and Iceland to Greenland.

But all the great foldings are only local and of slight importance in relation to the whole. I think that even these foldings may possibly be explained by the aid of our hypothesis. We shall presently see, how the hypothesis is able to explain great and extensive upheavals and subsidences. And great foldings must be produced at the division-line between parts of the crust, which move differently.

In the present state of our knowledge it cannot be demanded, that the hypothesis should be able to explain the distribution of land and sea upon our globe. The terrestrial geographical features are the result of a long evolution through many millions of years and under varying astronomical conditions. It is even possible, that the situation of the poles may be variable. We know very little about the youth of our earth, and the continents and oceans are of very ancient origin. We only have to take them as given magnitudes and try with the aid of our hypothesis to account for the changes, which are known to have taken place in later geological periods.

If we consider the Tertiary and Quaternary buildings of Europe, we see, that we may separate between great and slight displacements of the beach-lines. The slight displacements are proved by the numerous alternations of fresh-water, littoral and sublittoral sediments, which are found in the Tertiary basins and which enable us to distinguish between the geological stages. And as an instance of the great displacements, which mark the limit between geologic cycles, we may name the extensive and considerable risings, which in the Quaternary epoch took place under higher latitudes. Similar greater upheavals are exemplified, in the Miocene and Pliocene, by the emergence of several previously marine basins, as those of Paris, Vienna, Switzerland etc.

In examining the geological formations we find everywhere great breaks in the series of beds. In the Tertiary buildings we see frequent alternations of fresh-water, littoral and sublittoral beds, showing only inconsiderable displacements of the beach-lines. After such a series, corresponding to more or less geological stages, a break occurs, which often may represent several hundred thousands of years. These breaks commonly show, that the basin was lifted above the sea and that sedimentation was stopped. These greater upheavals were caused by strain accumulated through very long periods. Before this great strain was relieved, the basin was a weak part of the crust and was strained almost to the limit of elasticity. Slight forces were then sufficient to produce dislocations. Small changes in the magnitude of these forces were sufficient to cause small periodical displacements and intervals of repose. At last the great strain is relieved by a greater upheaval, and the basin is lifted above the sea. And as we have no proof to the contrary, it is allowed to suppose, that a long period of repose followed after the great upheaval. The uplifted basin now could lie undisturbed by earth movements for many hundred thousands of years. But by the lengthening of the sidereal day fresh strain accumulates. And the strain rises, as long as no displacements take place. The sea under higher latitudes rises slowly but uninterruptedly. After a long time the sea again inundates the basin. There is reason to believe, that the crust in the given place is now again strained almost to the limit of elasticity, as it has now again, in relation to the surface of the ocean, the same distance from the earth's centre, as it had before the last greater upheaval. It is then reasonable to suppose, that similar slight displacements will begin anew and that at last another greater upheaval will take place.

The displacements of the beach-lines, which enable us to divide between geological stages, were only slight and probably local. They were not contemporaneous everywhere. It seems, as though the forces were active at different times in different places. As in the present time some parts of the crust are weaker and more subject to earthquakes than others, so we must suppose was the case in Tertiary times too. If we disregard the Tertiary beds of the great folded chains and neighbouring regions, where great local upheavals and subsidences take place in relatively short time, we find, that the Tertiary layers are mostly fresh-water, littoral or sublittoral beds. An alternation of such sediments only points to slight displacements of the beach-line. *Edward Forbes*, in his Report on the Mollusca and Radiata of the Ægean Sea,[1] says: „A very slight depression of land in the Gulf of Macri on the coast of Lycia, would now plunge below the sea muddy tracts abounding in Melania, Melanopsis, Neritina and other fresh-water Mollusca. Their successors in the first formed shallows would be Cerithium mamillatum and a few bivalves. A drift of sand over this Cerithium mud would call into existence a new fauna and every successive depression or elevation, however slight, would produce considerable zoological changes, for the subdivisions of the uppermost region are of small extent in depth,[2] and very liable to be affected by secondary influences.“ How very slight these displacements were in many cases, we learn from the fact, that in the same estuary the same stage in some places is built through its whole vertical extent only of fresh-water beds, whilst in other places marine layers are intercalated in the middle, and that the relative thickness of fresh-water and marine layers may vary in different localities. We have several such instances in the fluvio-marine series of the Isle of Wight (Lower and Middle Headon etc). We thus see that the displacement of the beach-line was in such cases so slight as only to affect some parts of the estuary and not the whole.

I have above (p. 27—28) already pointed out, that, if a deep basin is cut off from the ocean by embankments, then a slight shift of the beach-line may be sufficient to cover or drain the bank, so that the basin may be alternately salt or fresh. In such deep basins, consequently, slight displacements of the beach-line may lead to an alternation of thick fresh- and salt-water layers, and all such alternating beds may even be deep-water formations.

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[1] Rep. Brit. Assoc. Adv. of Sci. London. 1844. p. 179.

[2] This region, according to *Forbes*, has a vertical extent of not more than 12 feet and may nevertheless be divided into subdivisions.

The shifts of the sea-level, indicated by the geological stages, were thus probably only very small.

And the great upheavals and subsidences are caused by strains, which have accumulated through very long periods. In Postglacial time great parts of the continents under higher latitudes have been considerably upheaved. The terraces and raised beaches tell that. In Norway the highest marine terraces are found up to 188 m. above the sea, but this is only the case in some places; commonly they lie much lower, and we would get a much lesser figure, if we were to give the mean value of the rising for the whole peninsula. In Arctic North America in some places there are marine traces up to 550 m. above the sea, but also here the mean value would be much less. If now it could be shown that such great and extensive upheavals were common in the course of time, the hypothesis no doubt would be quite insufficient to explain the facts. But the fact is that such upheavals are of rare occurrence. They only take place now and then after the lapse of very long periods. It is such great changes in the geographical conditions, which enable us to divide between geologic cycles, and they result from strains accumulated by the lengthening of the sidereal day through periods of time corresponding to whole cycles of the series. If that be remembered we should perhaps feel more confident that the hypothesis is probable.

We will now see, whether the hypothesis has for its disposal forces sufficient to account for the observed changes It is however impossible to make a definite calculation, because we do not know the speed, at which the sidereal day lengthens by tidal friction. We only know that it lengthens very slowly. Let us suppose the value of tidal retardation, experimentally calculated by Sir *William Thomson*, to be a probable one. The oceanic tide, according to that calculation, retards the rotation in a such degree that, after the expiry of 100000 years, the day is lengthened ten seconds. And in this calculation no heed is paid to the „bodily tides“ supposed by *G. Darwin* to act in the plastic mass of the globe. If we reckon only with the above named 10 seconds in 100000 years, then to this lengthening of the day corresponds a shortening of the equatorial radius of 5.6 m. and the double prolongation of the polar one, 11.2 m. If now we suppose the solid crust to lie undisturbed in 1½ million of years, which is the time corresponding to a geological cycle, we have a strain accumulated corresponding to an upheaval of the polar tract of 168 m. and a subsidence of the equatorial belt of 84 m. In this manner, even if the above named value of the retardation should be to high, very great and extensive upheavals and subsidences may take place in relatively short time, when strains accumulated through long periods are at last released.

The great transgressions of the sea in higher latitudes may also be explained by the hypothesis. In the times of transgression we must suppose, that the solid earth had come to depart much more from the figure of equilibrium than else. During these times the strain was accumulating, which afterwards caused the great upheavals. As the centrifugal force steadily diminishes, the sea always rises in higher latitudes. As long now as the solid crust remains unaffected, the sea under such latitudes must rise in relation to the land. If the crust lies undisturbed for 1½ million of years, the sea in polar regions will rise relatively to the land 168 m. It is clear that in this manner we are able to explain great transgressions by the aid of the hypothesis. A general rise of the sea level in higher latitudes of 100 m. or even more, whilst the solid earth lies undisturbed, will inundate large parts of the land and cause great changes in the distribution of land and sea. And the shorelines in higher latitudes may be brought to recede, either by the rising of the land in the same region or by the subsidence of the seabottom in lower latitudes.

During these transgressions the rising sea, as was shown by *Ramsay* and *v. Richthofen*, abraded the coasts, and extensive plains of denudation were formed, upon which fresh sediments were laid down unconformably upon the abraded tops of the old ones. We learn from that, how slowly and continuously the shores advanced upon the land. And this is just what we should expect, if it is the lengthening of the sidereal day, that causes the sea to rise.

At last the strain becomes so great, that the solid crust gives way, and the strain is relieved by great upheavals and subsidences. But these changes take place in relatively short time, if we may conclude from the teachings of geology.[1] And this also perfectly accords with the hypothesis.

It now only remains to account for the slight displacements of the beach-lines, which enable us to separate the geological stages. I have tried above to show that these displacements were only very small, that they were probably local and restricted to the weaker parts of the crust. As the stages, according to our hypothesis, represent intervals of time of 100000 years, the sea during this time will, under the latitudes of Middle Europe, rise some few metres, and that will probably be quite sufficient for the hypothesis.

We have seen above, that there is some reason to believe that earthquakes are more common, when the earth is in perihelion, at spring-tide, and under low barometric pressures. We have supposed that the upheavals and subsidences were caused by the summing up of the effects of innumerable small earthquakes or dislocations. We can now understand, that such dislocations should be more numerous and more considerable, when the eccentricity of the earth's orbit has a high value. Under such circumstances the earth in its perihelion approaches much more to the sun than else (more than 1 million geographical miles); the spring-tides are stronger; and the disturbances in the atmosphere probably greater. If we add that the tidal-forces vary directly with the eccentricity, and consequently that the strain accumulates with greater speed during high eccentricity; we must believe that all these things together will release strain and cause the great eccentricities to be accompanied, in weaker places of the crust, by such displacements of the beach-lines as those, to which the geological stages bear testimony.

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[1] „In diesen grössten Phasen fällt es aber auf, dass jene, welche am genauesten bekannt sind, dem positiven Theile eine weit grössere Zeitdauer zuzumessen scheinen als dem nachfolgenden negativen Theile.“ (*Suess*: Antl. d. Erde II. p. 686).

We know that the mean value of the eccentricity changes through long periods. In hundreds of thousands of years it sometimes is as low as 0.0208, whilst in other hundreds of thousands of years it may attain a value of 0.0340. And this probably must have effect. In those hundred thousands of years, when the mean value is greater, the strain will accumulate somewhat more quickly, and the mean effect of the releasing forces (nearness of the sun in perihelion, spring-tides, low barometric pressure) will also be greater. In Middle Europe great upheavals took place in the Miocene. In this epoch during volcanic eruptions several previously marine basins were lifted above the sea for long periods. But the movements are not synchronous everywhere. In England, for instance, Oligocene beds occur only in the southern parts, Pliocene only in the northern. And this probably shows, that the different parts of the country were upheaved at different times. And the great upheaval in the higher latitudes is of Post-Tertiary date. Marine Tertiary formations are rare in the Polar tracts. They are known to occur in Spitzbergen, Northeastern Greenland, and around the Bering Sea. But they are commonly wanting in those parts of the higher North, where marine terraces and raised beaches of Quaternary age are found. And in advancing southwards, we see in the Atlantic States of North America as well as in Europe and in Japan, that the southernmost Postglacial terraces are situated about at the same latitudes as the northernmost marine Tertiary formations. It is true, such formations may in many places have been destroyed by the glaciers of the Ice Age, but possibly also the movements of the solid crust took place both in a different manner and at different times in middle and higher latitudes. And this supposition agrees well with the opinion expressed by *Suess*,[1] that the great transgressions alternated in the lands bordering the Tertiary Mediterranean and in those around the Northern Seas.

The hypothesis does not demand that the upheavals should be everywhere contemporaneous, but only that they should occur especially after long periods with a higher mean value of the eccentricity, and such was the case both with the great Miocene rising in middle latitudes and the great Quaternary in higher ones.

We will next inquire, whether the hypothesis can account for the known climatic changes. For that reason we will first look at the map of the world.

The Pacific ocean only corresponds with the Polar sea through the narrow and shallow Bering Strait. No great warm current is able to pass trough this. But the Atlantic is open towards the North, and the warm North-Atlantic current washes the shores of Spitzbergen and Nova Zembla. Its effects are felt far into the Polar seas.

The mighty influence of these geographical facts is shown in the shape of the isothermes. In the Northern Atlantic they bend as tongues to the North, but at the Bering Strait they run parallel to the circles of latitude.

The changes of climate in Northern latitudes, during Tertiary and Quaternary times, were shortly the following:

The Ice Age was much more intense on both sides of the Northern Atlantic than at the Pacific. In Northwestern Europe, on the Faroe Islands, in Iceland, Greenland and Eastern North America the ice had an immense extension. In Eastern Asia and Western North America the signs of glaciation are much less prominent.

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[1] Antl. d. Erde II. p. 690.

The warm climate, which ruled in arctic and northern-temperate regions during a great part of the Tertiary period, appears, according to the present state of knowledge, to have been more pronounced in the lands at the North Atlantic than in those bordering the Northern Pacific.

Nathorst[1] has arranged the Tertiary floras of the higher latitudes according to the warmth, which they seem to indicate. If we begin with the floras demanding less, and finish with those demanding more warmth, we get the following order: Lena, New Siberian Islands, Kamtschatka, the Amur district, Sachalin, Spitzbergen, Grinnell Land, Buchtorma in the Altai, Mandchuria (two localities), Northern and Middle Japan, the Kirgise-Steppes, Alaska, Mackenzie, Greenland, Iceland, the Tertiary flora of the Baltic and at last the numerous other European localities. From this we see that, whereas during the Ice Age much more ice accumulated in the North Atlantic quarter, so in Tertiary times the warmth was much greater in this part than at the Pacific.[2]

As a possible resource in explaining the diversity of climate in Tertiary times in the different parts of the Northern regions *Nathorst* points to a displacement of the poles. He says, that astronomers have nothing to say against this supposition, if it should be thought necessary by geologists. But it should be kept in mind, that though astronomers hold changes of the terrestrial axis to be possible, still there are no astronomical reasons for believing that the pole in Tertiary times was situated at the place proposed by *Nathorst.* And it appears to me, that the named geological facts may perhaps be understood without the hypothesis of a displacement of the poles.

Nathorst puts the hypothetical Tertiary North Pole at lat. 70° and long. 120° E. Gr. But this is the situation of the present

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[1] Zur fossilen Flora Japans in Palæontol. Abhandl. herausgeg von *W. Dames* und *E. Kayser*. Vol. IV. Novbr. 8. 1888. p. 54.

[2] It should however be remembered, that, as *Nathorst* observes, these Tertiary floras possibly not all belong to the same epoch.

Siberian pole of greatest cold. We have now still another pole of cold in the arctic North America. And this last pole may perhaps be of later origin, it may perhaps be a result of the great Quaternary upheavals in arctic North America and of geographical changes, for instance in the regions about the Bering Strait.

From what has been said above it is clear, that no particularly great geographical changes are needed to effect a radical change in the climate of Northern polar regions. And we may conclude that such geographical changes have been more extensive in the Northern Atlantic than in the Northern Pacific, since we see, that the climatic changes were much greater in the first quarter than in the second.

The entrance to the northern parts of the two great oceans is barred by volcanic lines. South of the Bering Sea the volcanic line of Alaska and the Aleutian Islands runs across from continent to continent, and in the Northern Atlantic there is likewise a volcanic line, stretching from Iceland and the Faroe Islands along the submarine bank to Greenland and Scotland.

Such volcanic lines are lines of weakness in the crust, where we are allowed to expect greater disturbances and changes than elsewhere. The reader should look at the map, given by *Neumayr*[1] and representing the Mediterranean of the Older Pliocene, and he will at once see that in such volcanic regions great geographical changes occur in relatively short time.

And what a great influence would not be exercised on the climate of the polar and northern regions, if for instance the above named submarine bank from Scotland to Greenland should be lifted above the waters. Even if the land connection should not be quite complete, the warm current, which now has access to the polar seas, would be reduced, and the climate would be considerably deteriorated in all regions situated north of the bank. I have shown elsewhere, that there are good botanic reasons for believing, that Iceland, the Faroe

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[1] Erdgeschichte I p. 330.

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